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Corresponding Author: Enikõ Magyari, Ph.D.

Corresponding Author's Institution:

First Author: Enikõ Magyari, Ph.D.

Order of Authors: Enikõ Magyari, Ph.D.;John Chapman, Ph.D.;Andrew S. Fairbairn, Ph.D.;Mark Francis;Margarita de Guzman, Ph.D.

Abstract: In this article, we discuss the Neolithic and Early Copper Age (ECA) part of two pollen records from the Middle Tisza Floodplain in association with the local archaeological settlement record. We address the hypothesis of Willis and Bennett (2004) that there was little human impact by farmers on the environment of SE Europe until the Bronze Age. Contrary to this hypothesis, our results show that small-scale agriculture and woodland clearance is already attestable in the earliest Neolithic in Eastern Hungary, there are signs of expanding scale of mixed farming in the Middle Neolithic and very strong evidence for extensive landscape alterations with enhanced pasturing and mixed farming in the Late Neolithic (LN) and ECA. The main vegetation exploitation techniques in the alluvial plain of Sarló-hát were selective tree felling (mainly oak), coppicing (mainly hazel and elm), small-scale crop farming and woodland clearance to establish grazing pastures. Comparison with other well-dated pollen diagrams from Eastern Hungary suggested that, in the Early and Middle Neolithic (6000-5000 cal B.C.), hazel and elm coppicing were ubiquitous, while pastoral activities and associated woodland clearance distinguished the LN (5000-4500 cal B.C.). Comparison with regional and Northern Hemisphere paleoclimate proxy records suggested possible alignments between local environmental and Northern Hemisphere climatic fluctuations triggered by solar activity changes but, in several cases, climate change was attenuated by the buffering capacity of the floodplain (e.g. during the Szatmár II phase) or prevailed through transmissions modulated by precipitation and temperature changes in the watershed of the Tisza river (e.g. during the ECA). The interrelation between climatic and economic changes especially during the LN and ECA suggested a shift to moister summer conditions in the alluvium, which may contributed to decisions towards settlement dispersion and increased reliance on animal husbandry in the NE Hungarian Plain.

Enikő K. Magyari[1], John Chapman[2], Andrew S. Fairbairn[3], Mark Francis[4], Margarita de Guzman[5]

Neolithic human impact on the landscapes of North-East Hungary inferred from pollen and settlement records

[1]Hungarian Academy of Sciences - Hungarian Natural History Museum Research Group for Paleontology, 1476 Budapest, P. O. Box 222, Hungary
[2]Department of Archaeology, Durham University, South Road, Durham, DH1 3LE, United Kingdom
[3]School of Social Science, The University of Queensland, St Lucia, QLD 4072, Australia
[4] 10 Vara Drive, Belfast, Northern Ireland BT13 3BY
[5] Circle CRM Group Inc., 304, 716 - 3rd Avenue NW, Calgary, Alberta T2N 0J1, Canada

Correspondent author: Enikő K. Magyari, magyari@bot.nhmus.hu, tel.: +36705625614

Abstract
In this article, we discuss the Neolithic and Early Copper Age (ECA) part of two pollen records from the Middle Tisza Floodplain in association with the local archaeological settlement record. We address the hypothesis of Willis and Bennett (2004) that there was little human impact by farmers on the environment of SE Europe until the Bronze Age. Contrary to this hypothesis, our results show that small-scale agriculture and woodland clearance is already attestable in the earliest Neolithic in Eastern Hungary, there are signs of expanding scale of mixed farming in the Middle Neolithic and very strong evidence for extensive landscape alterations with enhanced pasturing and mixed farming in the Late Neolithic (LN) and ECA. The main vegetation exploitation techniques in the alluvial plain of Sarló-hát were selective tree felling (mainly oak), coppicing (mainly hazel and elm), small-scale crop farming and woodland clearance to establish grazing pastures. Comparison with other well-dated pollen diagrams from Eastern Hungary suggested that, in the Early and Middle Neolithic (6000-5000 cal B.C.), hazel and elm coppicing were ubiquitous, while pastoral activities and associated woodland clearance distinguished the LN (5000-4500 cal B.C.). Comparison with regional and Northern Hemisphere paleoclimate proxy records suggested possible alignments between local environmental and Northern Hemisphere climatic fluctuations triggered by solar activity changes but, in several cases, climate change was attenuated by the buffering capacity of the floodplain (e.g. during the Szatmár II phase) or prevailed through transmissions modulated by precipitation and temperature changes in the watershed of the Tisza river (e.g. during the ECA). The interrelation between climatic and economic changes especially during the LN and ECA suggested a shift to moister summer conditions in the alluvium, which may contributed to decisions towards settlement dispersion and increased reliance on animal husbandry in the NE Hungarian Plain.

Keywords: human impact, pollen analysis, archaeology, Neolithic, Great Hungarian Plain

Introduction

Ever since the interpretation of plant taxa from pollen records in terms of anthropogenic effects, there has been a debate about the extent of the impact of prehistoric cultivation and/or animal keeping on the contemporary environment (Iversen 1941; Lüning and Kalis 1992). In SE Europe, an area which was decisive in the early spread of agriculture, Willis and Bennett (1994) for example argued that there was little human impact by farmers on the environment until the Bronze Age. The implication is that, despite the large number of Neolithic and Copper Age settlements in this region (Marinova 2007; Marinova et al. this issue), their subsistence practices were relatively small-scale and they had little overall impact on their environments. It is a matter of regret that, with a few recent exceptions (e.g., Ecsegfalva: Whittle *et al.* 2007, Willis 2007), all of the pollen sites investigated so far in Hungary lie some distance from key early farming sites with well-dated on-site evidence for mixed farming (e.g. Willis et al. 1998, Sümegi 1999; Magyari et al. 2001; Gardner 2002; Magyari et al. 2008). This is also true of our paper, since the archaeological sites in question have not been excavated yet. Nonetheless, intensive fieldwalking has revealed well-dated surface artifact scatters, suggesting localised occupation near the pollen coring sites. The first aim of this paper is to address Willis and Bennett's hypothesis through the integration of palynological and archaeological data in a poorly known semi-arid river basin of North-East Hungary.

The identification of human impact in long-term pollen sequences leads to a second aim in this paper – the diagnosis of the relative importance of anthropogenic and climatic factors in accounting for major phases of cultural change. In recent decades, archaeologists have been extremely sceptical about invoking environmental factors to account for cultural and social change (Renfrew 1984). A recent example form Eastern Hungary is Parkinson's (2006) attempt to explain the shift from Late Neolithic settlement nucleation on tells and large flat sites to Early Copper Age dispersed farmsteads in terms of Johnson's (1984) 'scalar stress' hypothesis. In part, this is due to the difficulties in differentiating the impact of anthropogenic from climatic variables in the interpretation of pollen sequences (Behre 1981; Berglund 2003) and there is also the residue of the reaction against environmental determinism characteristic of some processual archaeologists (Jones et al. 1999) and environmental scientists (Kertész and Sümegi 1999). But the main reason for mistrusting a simple equation between climatic change and cultural and social change is the multi-level intervening variables that must be taken into account in such an assessment. The most obvious intervening variables are the settlement structure and the strategies for obtaining food and drink and specific preferences for plant and animal species; the buffering potential of successful participation in exchange networks; the overall cultural values which promote a specific life-style; and, last but not least, the options which people may or may not have chosen from the wide range of available options when faced by potential climatic change. Attention to some of these variables can create a framework for studying detailed regional and local palaeo-environmental data; a full consideration of all the associated cultural and symbolic variables goes beyond the boundaries of this paper. Here, two pollen cores from the Sarló-hát meander (Figure 1) provide a fine-grained record that can be interrogated to help in assessing the significance of climatic and cultural factors over the period of the Neolithic and Early Copper Age in North East Hungary (6000 – 4000 cal B.C.).

The occupation sequence in this micro-region is set against the framework of the regional settlement pattern, as documented in the Upper Tisza Project (Chapman et al. 2003, 2010a) and Hungarian investigations along the line of the M-3 Motorway (Hajdú and Nagy 1999; Raczky et al. 2007, 2011). The pollen cores are then used to determine local human impacts and wider regional climatic factors and to compare these results with the archaeological sequence. The paper concludes with an attempt to paint a broader picture of Neolithic and Early Copper Age subsistence through a comparison of the Sarló-hát diagrams with other coeval Hungarian pollen diagrams.

Materials and Methods

Study site

The oxbow lake of Sarló-hát is situated 2 km northwest of the village of Tiszagyulaháza in the northern part of the Great Hungarian Plain (Figure 1). Geomorphological and palaeoenvironmental investigation of the area started under the aegis of an Anglo-Hungarian interdisciplinary project, the Upper Tisza Project (Chapman et al. 2003).

The *Sarló-hát meander* (Figure 1c) lies in an area that has been the focus of settlement since the Early Middle Neolithic, owing to its wide range of productive habitats suitable for farming, animal husbandry, hunting and gathering. From the meander, two undisturbed sediment cores were taken, one from the vicinity of a site dominated by Middle Neolithic discard (SH-WOOD, ca. 20 m from the shore), the other near a site with signs of intensive Bronze Age discard and less intensive Middle Neolithic discard (SH-II, ca. 90 m from the shore) (Figures 1 and 2).

The study area is dominated by meadow soils (chernozems) on the Pleistocene elevated levees, and raw unstable soils on the floodplains (Chapman et al. 2003, 2010a). Parts of the Pleistocene levee localities are covered by saline soils (Marosi and Somogyi 1990), whereas, in the northern part of the area, brown-earth developed in very few places.

From the standpoint of climate, the northern part of the study area is relatively humid (annual precipitation: 600 mm); however, towards the south (Újtikos, Polgár: Figure 1) rainfall decreases abruptly, and in the Hortobágy hardly attains 500 mm (Szász and Tőkei 1997). The mean annual temperature ranges 9.7-9.9 ^{o}C. The difference between the mean temperature of the coldest and warmest months is also the greatest here in the Alföld, 22-24 ^{o}C. The above parameters would suggest a vegetation cover intermediate between steppe and warm temperate woodland (Walter 1974); on the basis of climatic parameters, Zólyomi (1946) described the potential vegetation of the area as warm continental forest steppe.

According to the results of geomorphological surveys, the Polgár landscape looked quite different in the Neolithic from today. Neotectonic subsidence and climate change over the last 30,000 years brought frequent and dramatic riverbed changes in this area (Borsy 1989; Tímár et al. 2005; Sümegi et al. 2005). The recently elevated, loess-mantled surfaces, where most Neolithic tells and settlements are found (Figure 2) are located in the southern part of the study area (e.g. Polgár Island on Figure 1c).

These are remnants of an ancient alluvial plain formed by the activity of NE-SW running rivers that drained the North Hungarian Mid Mountains and charged into the paleo-Tisza river that ran further south during the last glacial period (Sümegi et al. 2005). These large channels (e.g. Hódos-ér and Kengyel-ér on Figure 1c) and their alluvium accumulated loess, on which fertile chernozem soils developed in the early Holocene (Chapman et al. 2010a). Following a major Neotectonic subsidence, sometimes between 20-30,000 years ago (Tímár et al. 2005), the Tisza river was relocated into this area, and its meandering channels incised into the former alluvial surface developing a floodplain that now lies at 90-91.5 m, i.e. 2.5-4 m below the Late Pleistocene lag surface (Gillings 1997). In this landscape four lateglacial and Holocene channel generations were identified (Magyari et al. 2010). The Holocene rivers laid down silty deposits on which stray Neolithic finds, but also some settlements, were found (Figure 2). Overall, in the Neolithic period, the Pleistocene lag-surfaces were already in an elevated position, well above the level of the seasonal floods that on the other hand inundated lower lying areas below 91.5-92 m (Gillings 1998). The Sarló-hát meander is situated in the northern part of the Holocene alluvium, about 10 km away from the Polgár Island, but much nearer to a large, elevated Pleistocene sand and loess mantled hill near Tiszadob (1.5 - 2 km), where Middle and Late Neolithic discards are abundant, but so far tells were not found (Figure 2).

Using landscape morphological considerations, Sümegi et al. (2005) argued, that prior to the Neolithic occupation, the Pleistocene alluvial surfaces were covered by temperate wooded steppe and natural saline steppe communities in the ancient backswamp areas, with temperate gallery and floodplain forests probably on the Holocene alluvium. Since Neolithic occupation was mainly on the elevated surfaces, it is likely that Neolithic farmers/foragers/shepherds chose the naturally semi-open part of the landscape for settlement, where they cleared woodland stands. Little is known, however, about their impact on the alluvial forests. Our previously published paper from Sarló-hát suggested that this part of the Hungarian Plain supported oak wooded steppes throughout the Early and Middle Holocene and cultural steppe during the last 3,000 years (Chapman et al. 2009; Magyari et al. 2010). In the present paper, we examine how Neolithic land-use modified the species composition and spatial extent of the alluvial forests, and what sort of social practices (crop farming, gathering, coppicing, tree felling, burning) were established in the floodplain.

Fieldwork, laboratory and numerical analyses

Overlapping core sequences were collected from two localities in the palaeochannel using hand-held Russian and Livingstone piston corers (Figures 1c and 2).

The lithostratigraphy was described using the system of Troels-Smith (1955) as modified by Aaby and Digerfeldt (1986) and the physical characteristics of the sediment were determined by calculating loss of weight on ignition (Heiri et al. 2001). Subsamples of 1 cm^3 taken at 4-8 cm intervals were processed for pollen and microscopic charcoal analysis following method A of Berglund and Ralska-Jasiewiczowa (1986), with *Lycopodium* spore tablets used to determine concentrations (Stockmarr 1971). Pollen identification was performed using Moore et al. (1992), Reille (1992, 1995, 1998), and Punt *et al*. (1984) for a detailed identification of Umbelliferae pollen types. For this plant family a cumulative curve is displayed on the pollen diagrams that include the following pollen types: *Oenanthe*, *Cicuta*, *Angelica*, *Apium*-type and *Pastinaca*-type. A minimum of 500 terrestrial pollen grains per slide was counted concurrently with charcoal particles using the point count estimation method of Clark (1982).

AMS ^{14}C dating was performed by the Poznan Radiocarbon Laboratory on eleven terrestrial plant macrofossils and one mussel shell from core SH-WOOD.

Numerical analyses were performed using the routines within Psimpoll 4.10 (Bennett 1997). Pollen data was zoned by optimal splitting of information content; the age-depth relationship was modelled using Bayesian modelling (for details see Magyari et al. 2010); and rarefaction analysis were performed on pollen percentage data.

Estimation of anthropogenic disturbance on the natural vegetation

Human disturbance on the vegetation is often associated with increasing floristic diversity, with woodland clearance creating secondary habitats with rich herbaceous vegetation (Birks and Birks 1980). One way to make quantitative estimates of human impact on the natural vegetation is to apply diversity measures to fossil pollen spectra (Birks and Line 1992; Seppä 1998). We use rarefaction analysis for this purpose. All identified terrestrial pollen taxa were included and the basic pollen sum for calculations was set to $E(T_{500})$.

Pollen percentages of herbaceous indicator taxa were also invoked to characterise the land-use of the non-forested area. The categories considered are crop field, fallow and footpath ruderal communities, wet and dry meadows (Table 1). Herbaceous pollen types were assigned to these categories of land use according to previous studies as follows: (i) the anthropogenic indicator-species approach of Behre (1981); (ii) the ecological indications in the Hungarian flora according to Ujvárosi (1957) and Fekete et al. (1997). Percentages of the indicator species were pooled in each land-use category. Table 1 also provides information on the occurrence of these non-arboreal pollen types in natural vegetation types of the Middle Tisza Plain. As is evident from this table, several pollen-types considered as anthropogenic indicators are elements of the natural floodplain vegetation. The most problematic taxon is Chenopodiaceae. Species of this family grow preferably in floodplain ruderal mudflat communities and on saline lake bottoms (Table 1, Fekete et al. 1997). The former habitat appears in the seasonally flooded alluvium, where floodwater pools persist until mid-summer (Fekete et al. 1997). In the shallow nutrient rich water cyanobacteria and green algae produce large biomass (*Zygnema* and *Pediastrum* species) and after desiccation, the nutrient rich substrate becomes covered by fast growing annual ruderals (mainly *Chenopodium* and *Polygonum* species). Since we suspect that in the lakeshore SH-WOOD pollen record and possibly also in the lake-central SH-II pollen record Cheneopodiaceae pollen was mainly derived from these natural communities during the Neolithic (see further discussion below), we excluded this taxon from the anthropogenic indicator list (Table 1).

Spatial representation of the pollen and microcharcoal records

Modelling and empirical studies (Sugita, 1993, 2007ab; Soepboer et al., 2007) indicate that for a lake such as Sarló-hát (elongated oxbow lake with 200–240 m diameter today and ca. 960 m diameter mire with a central island in the past, see Figure 1b), the correlation between pollen abundances and vegetation composition is not improved by considering vegetation more than 400–600 m from the lake. The regionally ‘uniform’ background pollen component, representing vegetation between 600 m and tens of kilometres from the lake, accounts for ca. 45% of the total pollen (Soepboer et al. 2007). The Sarló-hát pollen data thus provide an integrated palaeovegetation record for the landscape around the lake and the surrounding region, with pollen from extra-local (20 m - 2 km) and regional sources (2 km - 200 km) predominating. Assuming a prevailing northerly wind direction in the past, as at present, the regional and extra-regional components principally reflect the vegetation of the Taktaköz and southern North Hungarian Mid Mountains (Figure 2b). Pollen from local sources, up to tens of metres from the sampling point, will be better represented in the SH-WOOD lake margin core than in the central SH-II core.

Charcoal contained in lake sediments is an important proxy for fire and has been extensively used as an indicator of past burning regimes (Tinner et al. 2005; Colomabroli et al. 2008). Microscopic charcoal records (particles between 20-180 μm in our case) can be representative of both local and regional signal of burning (Whitlock and Larsen 2001), and similarly to the empirical relationships with pollen, the diameter of the lake basin can influence the proportion of charcoal received from a regional or local source. Our microscopic charcoal record comes from the lake-marginal SH-WOOD core. This location is expected to receive a greater amount of input from the environment immediately around the basin, because the lake surface area is relatively small in this position relative to the edge area, which acts against large-scale aerial transport (Whitlock and Larsen 2001). Therefore, the microscopic charcoal record from SH-WOOD is expected to hold a strong local and extra-local fire history component beside the regional signal.

Archaeological fieldwalking

The fieldwalking in the Tiszagyulaháza area was carried out by staff and experienced students, using the tried and tested techniques of the Upper Tisza Project in the Polgár Block (Chapman et al. 2003, 2010a). This involved walking in parallel lines at 10m spacing across the main axes of ploughed fields. A total of 0.6 km^2 (Figure 1) was covered in this way in 12 person-days, indicating a mean of 20 person-days per sq. km., which shows moderately high fieldwalking intensity for such conditions. This spacing of fieldwalkers meant that not only were no ‘site scatters’ missed but that there was a high probability of the recording of single finds (or ‘off-site’ discard) near the sites.

Results

The Sarló-hát archaeological survey

Earlier systematic fieldwalking by the Upper Tisza Project led into the mapping of Neolithic sites and stray finds in the Polgár area. These data are presented on Figure 2 and show that the earliest Neolithic discard belongs to the Early Middle Neolithic Szatmár II group dating between 7450-7250 cal B.P. (5500-5300 cal B.C.). Site and discard densities increase in the Middle Neolithic AVK (Alföld Linear Pottery) cultural phase (7250-6950 cal B.P., 5300-5000 cal B.C.), which is followed by smaller number of large Late Neolithic sites belonging to the Tisza-Herpály-Csőszhalom (THCS) cultures (6950-6450 cal B.P., 5000-4500 cal B.C.) (Chapman 1994; Raczky and Anders 2008). Despite the relatively low number of sites, population density was the highest in the Late Neolithic, as the nucleated horizontal settlement at Csőszhalom had in itself 2100-2600 inhabitants (Raczky et al. 2002). In the Early Copper Age (not shown on Figure 2), a small number of scattered sites (probably farmsteads) were found in the Polgár area suggesting settlement dispersion and decreasing human population (Chapman 1994).

Our intensive, systematic fieldwalking around the Sarló-hát meander led to the discovery of five new sites on the lakeshore (Figure 3):

Tiszagyulaháza 9 is a 0.4-ha multi-period site on the North slope of a low hill. Widespread and dense Middle Neolithic discard was found, with one 40 x 10m concentration, partially overlapping with daub and lithic concentrations; low-density Copper Age discard; undated lithics, daub and ground stone discard. No magnetic anomalies were located and no cultural material was found in the single soil core.
Tiszadob 28 is a 0.4-ha multi-period site on the South slope of a low hill, 100m North of the SH-II pollen core. Widespread and dense Middle Neolithic (Tiszadob group) discard was found with one 40 x 40m concentration that matches one large and two small magnetic anomalies as well as three soil cores with signs of a cultural layer and the highest soil phosphate values; strong overlap with lithic and daub concentrations and some overlap with the ground stone discard; small low-density Copper Age discard, with Early Copper Age finds in one grid square.
Tiszadob 29 had one Middle Neolithic sherd and 10 lithics in a scatter measuring 40 x 40m. There was no evidence of a cultural layer in the single soil core and no magnetic anomalies were detected.
Tiszadob 30 had a generally low-density discard. It is a 0.1-ha multi-period site on the South slope of a low hill with widespread Middle Neolithic discard but lacking sherd concentrations; small, high-density Copper Age discard, relating to the discovery of a perforated polished stone axe fragment and a lithic peak in the same grid square as the soil core, which showed evidence of daub fragments at depth; ground stone discard more widespread than on most other sites. No magnetic anomalies were recorded.
Tiszadob 31 is a 0.5-ha multi-period site on the South slope of a low hill, 50m North of the SH-WOOD pollen core. It had small Early Middle Neolithic (Szatmár II) discard in one grid square where the soil core shows signs of a cultural layer and possibly a pit; widespread but discontinuous Middle Neolithic (Tiszadob group) discard, with two sherd concentrations measuring 30 x 10m and 30 x 20m respectively, both concentrations match magnetic anomalies and soil cores with traces of a cultural layer and overlap with lithic concentrations; discontinuous, low-density Copper Age discard, including some Late Copper Age material, with a peak in one grid square; traces of a cultural layer in one soil core.
These findings may be interpreted as indications of diachronic changes in the intensity of occupation around the Sarló-hát meander. After a small and/or short-lived Early Middle Neolithic (Szatmár II) discard, there was varied Middle Neolithic (Tiszadob group) discard on four of the five sites, with traces of cultural layers in the soil coring, magnetic anomalies, daub and lithic concentrations in two sites. Notable is the total absence of Late Neolithic ceramic discard, while two small low-density scatters were dated respectively to the Early and the Late Copper Age, with a cultural layer in the latter.

Sediment lithostratigraphy, radiocarbon dating and age-depth modelling

Figure 4 displays the sediment stratigraphies, loss-on-ignition results from SH-II and SH-WOOD, uncalibrated ^{14}C dates and the Bayesian age–depth model for the SH-WOOD core. This core was dated by 12 AMS ^{14}C dates. Because no material suitable for ^{14}C age determinations was found in core SH-II, the age–depth model for this core was estimated using age estimates from the SH-WOOD core for pollen stratigraphical features apparent in both diagrams and used to define LPAZ boundaries. Further details on the chronology are discussed in Magyari et al. (2010).

Four principal lithostratigraphic units were recognized in both cores (Figure 4). Fluvial sands forming the lower parts of both sequences were overlain by silty clay and fine silt layers, and the Neolithic/ Early Copper Age (ECA) sediment layers were dominated by claysilt in both cores with no sign of mottling suggesting that these layers were not affected by periodic ground water fluctuation. Sand lenses were also missing, indicating stable lake conditions and no direct flooding of the core locations during the Neolithic and ECA. Organic content was generally low in the lake-central SH-II core; typical values were around 7-10%, with a single peak of 14% at 6400 cal B.P. Notable is that, in SH-WOOD, increased organic content (12-13%) was detected between ca. 8350 and 7000 cal B.P. (279–234 cm) coinciding with the pre-Neolithic, Early and Middle Neolithic periods, followed by a return to lower values (8-9%) during the Late Neolithic and ECA. Similar changes were not seen in the SH-II core.

The pollen records

The relative frequency distributions of selected terrestrial pollen types from the lakeshore SH-WOOD and lake-central SH-II profiles are plotted on Figures 5 and 6, while wetland and aquatic pollen types from SH-WOOD are shown in Figure 7. In order to aid the interpretation of the vegetation changes, Table 2 summarizes the pollen results by providing averages of the most characteristic arboreal and herbaceous pollen types for each Neolithic and Early Copper Age cultural period, as well as microcharcoal concentrations and palynological richness. Figure 8 shows cumulative pollen curves for the various land use categories according to Table 1. The following interpretation of the Neolithic and Early Copper Age vegetation changes are based on these results. Nine pollen assemblage zones have been defined in both pollen diagrams (see Magyari et al. 2010). The Neolithic period is part of the longest assemblage zone SH-5 (between 8400-5400 cal B.P.), which is characterised by frequent, small-scale pollen frequency changes, but is otherwise the longest Holocene period with stable oak- (*Quercus*), hazel- (*Corylus*) and elm- (*Ulmus*) dominated arboreal pollen assemblages and 30-40% herbaceous pollen (NAP) whose grasses (Poaceae), wormwoods (*Artemisia*) and chenopods (Chenopodiaceae) are the most prominent. The two pollen diagrams indicate that, in the early Holocene, the vegetation of the higher floodplain around the Sarló-hát meander consisted of alternating patches of mixed hazel-oak-elm (*Corylus-Quercus-Ulmus*) woodland and continental steppe vegetation (Figures 5 and 6; Magyari et al. 2010). Along the channels, gallery-forests rich in willow (Salix), ash (*Fraxinus excelsior*/*angustifolia*) and oak (*Quercus*) were characteristic. A major change in this vegetation took place around 8400 cal B.P., i.e. about 1000 years earlier than the first Neolithic settlers appeared in the region.

Pre-Neolithic vegetation changes (8400 – 7950 cal B.P.; 6450 – 6000 cal B.C.)

Changes in the pollen assemblages are prominent in both the terrestrial and aquatic records at 8400 cal B.P. (6450 cal B.C.). Most conspicuous is a shift from hazel (*Corylus*) to oak (*Quercus)* dominance in both pollen records, and a decrease in ash (*Fraxinus excelsior/angustifolia*) in the lakeshore SH-WOOD record (Figure 5). These imply a change from hazel-, oak- and ash-dominated forests to oak- and elm- (*Ulmus*) dominated forests in the floodplain. Relatively high arboreal pollen frequencies (70-75% AP) in both records furthermore suggest that the woodland cover probably reached its Early-Mid Holocene maximum, with oak-wooded steppes on the elevated Pleistocene levees ('Polgár Island' and 'Tiszadob Island' *sensu* Sümegi et al. 2005) and oak-hazel-elm-ash forests in the seasonally flooded alluvium (Figures 1 and 4). The combination of woodland compositional change and high microcharcoal concentrations between 8500-8200 cal B.P. (6550 – 6250 cal B.C.) suggests that woodland fires probably facilitated the spread of oak, as well as the small-scale temporary spread of beech (*Fagus*) (2.5% at 8100 cal B.P.) (6150 cal B.C.).

The herbaceous pollen flora showed different changes in the two pollen records. An increase in chenopods (Chenopodiaceae) and sorrel (*Rumex acetosa/acetosella*) characterised the lakeshore SH-WOOD, while cereal pollen was detected in nearly all samples after 8500 cal B.P. (6550 cal B.C.) in both records. Unfortunately, none of the aforementioned herbs can be treated as definitive indicators of human impact in this region. As discussed in Magyari et al. (2010), chenopods and sorrels can both live on the seasonally exposed bottoms of the palaeochannels in saline and ephemeral plant communities, but they are also characteristic plants of paths, disturbed land surfaces, crop fields and pastures (Behre 1981; Fekete et al. 1997). Wild cereals can also be natural constituents of oak wooded steppes (e.g. *Hordeum hystrix* and *H. secalinum*). Wild rye (*Secale sylvestre*) is also a typical natural constituent of open calcareous sand meadows in the Danube-Tisza Interfluve, but it does not appear in the less calcareous sand areas of the NE Hungarian Plain (Fekete et al. 1997). Overall, the herbaceous pollen flora can be indicative of both natural processes, i.e. enhanced seasonal fluctuation in the water-level and hence seasonally exposed lakeshore with ephemeral and saline vegetation, and anthropogenic landscape disturbance as foragers opened up clearings for more effective hunting and gathering. Taken together with changes in the wetland pollen record in this period, such as the decreasing abundance of open-water indicator green algae (*Pediastrum boryanum* and *P. simplex*), a rapid increase of lakeshore-dwelling galingale (*Cyperus*), floating fern (*Salvinia natans*) and redshank (*Polygonum persicaria*) and the increasing sediment organic content, we interpreted these changes as reflecting an enhanced seasonal lake-level fluctuation with high spring and early summer water table followed by midsummer lake desiccation and proliferation of ruderal mudflat communities and pioneer floodplain vegetation with *Cyperus fuscus* on the lakeshore (Magyari et al. 2010) rather than human disturbance of the terrestrial vegetation, although the latter cannot be ruled out. Palynological richness was stable in both records in this period (20-23) suggesting that the woodland compositional change did not affect the herb flora and was associated with minimal disturbance. In SH-WOOD a single peak in palynological richness is seen in the uppermost sample, at 7950 cal B.P. (27), this coincides with a decrease in AP:NAP ratios and may suggest woodland disturbance in the vicinity of this core.

Early Neolithic vegetation changes (Körös Culture with no settlement evidence: 7950 – 7450 cal B.P.; 6000 – 5500 cal B.C.)

Although local settlement is not indicated by archaeological fieldwalking, the fall in arboreal pollen percentages and AP:NAP ratios between 7950 and 7450 cal B.P. (6000 – 5500 cal B.C.) in SH-WOOD suggests small-scale forest clearance in the vicinity of the meander. Hazel and oak were probably both felled, with the saw-toothed pollen curves implying periodic clearances already in this period. It is notable that microcharcoal concentrations decreased in this phase, suggesting that the woodland was not burnt but, rather, that trees were selectively removed. In the case of hazel, coppicing may also be assumed. Since similar changes are not detectable in the lake-central SH-II pollen record, we assume that forest disturbance was confined to the small hill directly North of the meander in the vicinity of SH-WOOD (Figures 1-3). The increasing abundance of chenopods (Chenopodiaceae) in this period in SH-WOOD, together with sedge (Cyperaceae) and galingale (*Cyperus*) pollen percentages, suggests low summer water levels and further lakeward expansion of the wetland macrophytes. The continuous nature of the cereal pollen curve in this period in SH-WOOD, with wheat (*Triticum*-type) pollen grains at the end of this phase, (Figure 8) may suggests small-scale crop farming after 7600 cal B.P. (5650 cal B.C.). The absence of cereal pollen types in SH-II supports the local source of the cereal pollen in SH-WOOD. Palynological richness values showed no change in SH-II relative to the pre-Neolithic period, suggesting no major disturbance in the vicinity of this core, in line with the pollen record. In SH-WOOD however, peak terrestrial pollen diversity values at 7900 cal B.P. were followed by a drop (from 27 to 18), and increased values followed afterwards. This may imply vegetation reorganization after a single disturbance event at 7900 cal B.P. Overall, evidence for vegetation disturbance and crop farming is strong in the SH-WOOD pollen record in contrast to the lack of sites dating to the Early Neolithic.

Middle Neolithic vegetation changes (Szatmár II and Early AVK: 7450 – 7250 cal B.P.; 5500 -5300 cal B.C.)

The burning of woodland is suggested by the continuous decrease in AP:NAP ratios and total arboreal pollen abundance in the first part of this short occupation phase in both records, that is associated with a microcharcoal concentration peak at 7280 cal B.P. (5330 cal B.C.) in SH-WOOD. The decrease of mainly hazel in both records is conspicuous and may suggest its selective felling or coppicing. Towards the end of this phase, a short term woodland recovery can be inferred from the total arboreal pollen, oak and ash pollen percentage increases in the vicinity of SH-WOOD.
The appearance of cereal (*Triticum*-type and *Secale*) and crop-field weed pollen types especially in SH-II but also in SH-WOOD suggest small-scale crop farming in the vicinity of the meander (Figure 7).

There is a further notable change in the wetland pollen and green algae records, where a small increase in *Pediastrum boryanum* and *P. simplex* indicates temporary increases in the lake-level (Figure 7). On the other hand, the Szatmár II cultural period also coincides with the spread of Redshank (*Polygonum persicaria*-type, likely P. *periscaria* or *P. hydrolapathum*) in SH-WOOD that is indicative of wet meadows and seasonally exposed mudflat communities on the lakeshore. Redshank is a natural element of the alluvial landscapes, but also a weed occurring in nitrogen-rich disturbed habitats and even in wet crop fields (Fekete et al. 1997). Its continuous pollen curve in SH-WOOD starting in the Szatmár II period is likely to reflect the natural succession of the landscape, but an anthropogenic spread cannot be ruled out. In line with the decreasing AP frequencies in SH-II, palynological diversity shows a prominent peak in this record (26) suggesting that episodic woodland clearance probably opened up the forest canopy allowing for the spread of herbs. It is notable that the pollen-inferred human impact on the vegetation is stronger in the vicinity of SH-II, even though Early Middle Neolithic (Szatmár II) discards were recovered in the vicinity of SH-WOOD (Dob 31, Figure 3).

Middle Neolithic vegetation changes (Late AVK with strong archaeological evidence for occupation: 7250 – 6950 cal B.P.; 5300 – 5000 cal B.C.)

The most remarkable change that can be associated with human impact is the increase of wormwood (*Artemisia*) pollen abundances in SH-WOOD, indicating the expansion of alluvial pasture. Wormwood pollen abundances do not increase in SH-II, confirming that it spread locally in the vicinity of SH-WOOD, where two late AVK sites were detected by fieldwalking (Dob 29 and 30 on Figure 3). Since most wormwood species living in the north-east Hungary today are unpalatable to cattle and sheep, and are also favoured by soil nitrogen enrichment (especially *A. vulgaris*, Ujvárosi 1957, Molnár 1996; Fekete et al. 1997), grazing increases their abundance in pastureland, and this is the probable explanation of their pollen increase in this phase. After a short recovery, the woodland cover decreased again during the late AVK occupation phase around SH-WOOD, but increasing AP% and AP:NAP ratios in SH-II suggest a woodland recovery in this part of the meander. High ash (*Fraxinus excelsior/angustifolia*) pollen frequencies in SH-WOOD probably indicate a secondary woodland succession following the clearance episodes. Somewhat surprisingly, palynological diversity decreased in this cultural phase in both pollen records (Figures 5 and 6), despite the evidence for woodland clearance and increasing meadow cover in the alluvium.

Late Neolithic vegetation changes (Tisza-Herpály-Csőszhalom group with major occupation in the Polgár Block but no archaeological evidence for occupation in the Sarló-hát area: 6950 – 6450 cal B.P.; 5000 – 4500 cal B.C.)

Rye (*Secale*) pollen is present in SH-WOOD all-along in this cultural period that together with the occurrence of crop field indicator weeds likely indicate crop fields in the vicinity of the meander. Its co-occurrence with wheat (*Triticum*-type) and other cereal pollen suggests that rye pollen more likely derived from crop-fields than the natural steppes. Similarly to the AVK phase, the high values of wormwood (*Artemisia*) pollen in SH-WOOD point to the ongoing use of the floodplain for pasture. Moreover, the combination of decreasing AP:NAP ratios in SH-WOOD with a microcharcoal concentration peak at 6890 cal BP (4940 cal B.C.) suggests that selective felling and woodland burning were both frequent occurrences in the vicinity of the meander near SH-WOOD. Furthermore, several features of the SH-WOOD pollen record imply that the alluvium became wetter during the summer months. The gradual increase in Umbelliferae pollen abundances (with its characteristic components: *Oenanthe*, *Cicuta*-type, *Angelica* and *Pastinaca*-type) and the fall in organic content, sedge and galingale pollen abundance all imply less severe seasonal fluctuation in the water table and slightly decreasing productivity in the lake. These Umbelliferae forbs prefer wet meadows with a seasonally more stable water level than seasonal ruderals (Fekete et al. 1997; Magyari et al. 2010). It is notable that the SH-II pollen record does not indicate strong human impact on the vegetation in this cultural phase, in contrast with the SH-WOOD record. The most prominent feature is the increase of hazel (*Corylus*) pollen against oak (*Quercus*) that may indicate selective felling of oak trees. Palynological richness values are stable in SH-II, while they show a strong increase in SH-WOOD (Figure 5), supporting stronger vegetation disturbance in the vicinity of this core, although Late Neolithic discards were not found in the vicinity of Sarló-hát.

Early Copper Age vegetation changes (Tiszapolgár group with limited archaeological evidence for occupation: 6450 – 5950 cal B.P.; 4500 – 4000 cal B.C.)

The most remarkable change at the onset of this occupation phase is the rapid increase in pollen types indicating wet meadows, mainly in SH-WOOD. The probably rapid expansion of Umbelliferae forbs in the lakeshore suggests a further increase in summer water-table stability. The rise in hazel pollen percentages as compared to oak suggests either the cessation of Neolithic practices of woodland management (hazel coppicing, leaf foddering) or the selective felling of oak. Decreasing AP abundances are accompanied by a microcharcoal concentration peak at 6150 cal B.P. (4200 cal B.C.) in SH-WOOD, indicative of episodic woodland clearances by burning. That clearings were probably made in the high-floodplain zone can be inferred from the post-fire expansion of ash (*Fraxinus excelsior/angustifolia*) in SH-WOOD, probably indicating a secondary woodland succession following the disturbance event. The absence of Rye (*Secale*) in the cereal pollen and only sporadic wheat (*Triticum*-type) pollen occurrence in SH-II with arable weeds in both pollen records means that the evidence for crop fields in the alluvium in the Early Copper Age is ambiguous. Overall, our results suggest continuing human impact in the floodplain, with strong evidence for episodic woodland clearances and a probably climatic-induced change in the wetland vegetation of the floodplain.

Discussion

Contrasting the archaeological evidence for occupation with pollen-based inferences on human impact on the alluvial vegetation

The early – middle 6th millennium cal B.C.: the first farmers in North East Hungary?

The archaeological record from the Polgár area provided no evidence so far for occupation in the Earliest Neolithic (Körös / Criş groups) (Chapman 1994, Chapman et al. 2010a, Raczky et al. 1994, 2008, 2011). The pollen record, on the other hand, hinted at episodic woodland clearances and selective felling or coppicing of hazel in this period (7950-7450 cal B.P.; 6000 – 5500 cal B.C.) and *Triticum*-type pollen was also recorded suggesting small-scale crop farming (Figure 8). So the two records are seemingly in discrepancy with each other for the Earliest Neolithic. Although hypothetical, this paradox can be explained in several ways. One would be the burying of small Körös sites by alluvial deposits or their reduced artefact discard related to short-lived or seasonal occupations. Körös sites are usually found in elevated relic channel banks or natural levees (Nandris 1970, Kosse 1979, Sherratt

1982/3; Gillings 2007). However the recent discovery of several small sites in the north GHP on less elevated terrain (Domboróczki 2005; Domboróczki and Raczky 2010) may suggest the possibility of hitherto undetected sites buried under alluvium or hillwash, even in survey blocks where there has been intensive systematic fieldwalking (e.g., Blocks 1 and 2 of the Upper Tisza Project: Chapman et al. 2010a, 2010b).

The second possibility is that some Szatmár II sites may date earlier than suggested by Hertelendi et al. (1995). In this respect the radiocarbon dates of recently discovered northernmost Körös sites (Tiszaszőlős-Domaháza-puszta and Ibrány-Nagyerdő) are important. They date around 7550-7450 cal B.P. (5600 – 5500 cal B.C.) (Domboróczki 2005; Domboróczki and Raczky 2010), indicating a chronological as well as a spatial overlap with Szatmár II populations. This overlap mirrors the overlaps between the Körös and the Szatmár II groups in the south Alföld, suggesting continuity in material culture development across the Early – Middle Neolithic transition.

Finally, it is also possible that we see the impact of Mesolithic foragers between 7950-7450 cal B.P. (6000 – 5500 cal B.C.). In this respect, contrasting opinions have been formulated by Domboróczki (2005) and Sümegi and Kertész (1998). While the first author argues that the Mesolithic population was too small to exert any influence on the southern Körös sites and probably also on the natural vegetation, the second two authors suggested that a relatively large Mesolithic population lived north of the river Körös, whose environmental impact is detectable in several East Hungarian pollen records (Sümegi 2005). According to the interpretation of Sümegi (2005) and Juhász (2007) (cf. Zvelebil 1994), Mesolithic hunter-gatherers regularly burnt the early Holocene mixed forests down to create hunting trails and clearings, as well as promoting the spread of hazel and other edible species. A similar interpretation was provided by Kuneš et al. (2008) in the Czech Republic on the basis of a strong correlation between local hazel pollen peaks and Mesolithic intensity of occupation. However, if we look at the Sarló-hát pollen records (Figures 5 and 6), forest fires in fact decreased in the period under consideration, and hazel pollen declined periodically in this period, suggesting that the classical Mesolithic land-use strategy cannot be invoked to interpret anthropogenic vegetation changes. Overall, it is less likely that we see the impact of Mesolithic groups here in comparison with undetected Early Neolithic groups acting as triggers of the detected vegetation changes. However, it remains an open question whether the pollen-inferred vegetation disturbances in the Sarló-hát pollen records are attributable to early, undetected Körös groups or late hunter-gatherer communities who practised incipient cultivation, as in other areas of Europe (cf. Poska et al. 2004; Tinner et al. 2007).

In the subsequent Early Middle Neolithic Szatmár II phase, fieldwalking disclosed several stray finds in the vicinity of the Sarló-hát meander, pointing to low-intensity occupation on the lakeshore. This agrees well with the pollen-inferred evidence for increasing woodland clearance at 7400 cal B.P. (5450 cal B.C.) that probably involved 'slash-and-burn' clearance as reflected by a single microcharcoal peak in SH-WOOD. We found cereal pollen and crop field indicator weeds in SH-II, which lies further from the registered Szatmár II sites than SH-WOOD (Tiszadob 31; Figure 3). Thus, the pollen and archaeological records support each other and refer to the likelihood of small-scale crop-farming on the small hill 'Renyő-hát' that lies North-East of the study site (Figure 1). This is an important result for the Szatmár II group, whose settlement traces are often slight since a high residential mobility is implied by the small number of small, widely-spaced sites (Chapman et al. 2003).

The late 6th millennium cal B.C.: changes in farming practices

Middle Neolithic AVK groups using Tiszadob-style pottery were the most abundant in the alluvial zone around Sarló-hát. Discard was found on four out of the five sites, all suggesting permanent occupation or seasonal activities near the floodplain zone. It is notable that both pollen records suggest a short oak woodland recovery between the Szatmár II and AVK occupation phases. This is followed by a clear AVK-associated oak clearance, periodic hazel coppicing and woodland burning that probably favoured the temporary spread of ash (*Fraxinus excelsior/angustifolia*) and dewberry (*Rubus*). Since ash is a typical re-sprouter and pioneer tree in the floodplain woodlands, its spread indicates woodland recovery after clearance (Fekete et al. 1997). Overall, the increased evidence for human modification of the floodplain zone for wetland pasture is well matched by the increased exploitation of the oak woodlands.

Middle Neolithic (AVK) settlement represents the peak of dispersion in the Neolithic (Figure 3), with a larger number of smaller sites than in the Early Neolithic of southern Hungary (Sherratt 1982/3; Makkay 1982a). The discard traces around the Sarló-hát lake are typical of the smaller range of AVK settlement clusters found in the Békés County surveys of the Hungarian Archaeological Topography (Ecsedy et al. 1982, Jankovitch et al. 1989, Chapman 1997). What is interesting is that there is a stronger pastoral than arable signal in the AVK segment of the pollen cores – perhaps an indication of an early emphasis on cattle and caprine husbandry in alluvial pastures but also with cereal cultivation in a mixed farming system. The inference of an AVK manuring scatter from field survey evidence in Multi-Community Zone 12, near the village of Timár, in the Upper Tisza Project Block II, (Chapman and Laszlovszky1993; Chapman et al. 2010b) supports the idea of the integration of farming with a pastoralist (animal manure) input. The high residential mobility of AVK sites fits well with the notion of a low-intensity farming regime.

The Late Neolithic – a boom in cattle husbandry?

The Late Neolithic is a period of maximum settlement nucleation in Eastern Hungary (Makkay 1982b; Kalicz and Raczky 1989; Parkinson 2006). Parkinson (2006: 139 – 156) characterises the settlement pattern of this period as a small number of clusters of tightly grouped sites in a river valley, with sites grouped around a central ‘super-site’ (open site or tell). These clusters were separated by large expanses of seemingly ‘unoccupied’ territories, often with just as high a land-use potential as the settled areas. It appears at first sight that Sarló-hát lay in one such unoccupied tract, since there was discard of not a single sherd of Late Neolithic pottery. Some 10km to the South lay the tell and horizontal settlement of Polgár-Csőszhalom, acting as the local ritual centre for a Late Neolithic cluster, at the heart of an extensive exchange network based on limnoquartzite, rocks for polished stone tools, pottery and some obsidian (Raczky et al. 2002, 2007; Chapman et al. 2010a).

Despite the lack of evidence for local sites, the lakeshore SH-WOOD pollen profile provided evidence for a major change in the scale of floodplain exploitation. The expansion of floodplain, lakeshore pastures shows more intensive pastoralist clearances than in the AVK phase. Open vegetation probably replaced some of the lakeshore oak-ash-elm woods and must have served for grazing. The creation of floodplain pastures probably reflects improved land management in this phase, but it is also conceivable that cooler and wetter summers in the Late Neolithic mitigated against cultivation, making more viable the practice of extensive pasturing, which is reflected in deforestation and grassland and meadow expansion in the Sarló-hát pollen diagrams. A similar shift towards extensive pasturing was observed and connected to climate change in several Neolithic pollen records in NW Europe (Berglund 2003). On the other hand, the archaeological and archaeobotanical records from Polgár provide evidence for technological improvement, as a greater diversity of crops and more integrated agro-pastoral strategies were found (Fairbairn 1992, 1993; Raczky et al. 2011). In addition, crop field indicator weeds and cereal pollen representing some of the species found in the Late Neolithic plant assemblage at Csőszhalom (Fairbairn 1992) were found in the SH-WOOD profile (see below), probably reflecting the increasing area covered by crop-fields and open steppe-like disturbed vegetation.

The discrepancy between the archaeological and the palaeo-botanical data at Sarló-hát is greatest in the Late Neolithic, given that this local area lay within one of the so-called ‘unoccupied’ territories between Late Neolithic settlement clusters. Two possible explanations may be proposed. The first explanation is that intensive, systematic survey has not been carried out for an area between Sarló-hát and the reasonably completely surveyed ‘Tiszadob Island’ (Chapman et al. 2003). It is thus possible that a small to medium-sized Late Neolithic connected to the mixed farming around Sarló-hát may yet be discovered South of the ‘Tiszadob Island’. By contrast, between Sarló-hát and Csőszhalom, but closer to the former, lay two small Late Neolithic sites – a very small (20 x 20m) high-density cluster (Tiszagyulaháza 002) and a low-density scatter covering 0.5 ha (Tiszagyulaháza 005). One further low-intensity Late Neolithic scatter lay North of Sarló-hát on the ‘Tiszadob Island’ – Tiszadob 001 (0.5 ha) (Chapman et al. 1993). Each of these unexcavated sites are consistent with small rural sites, perhaps dispersed ‘homesteads’ or even summer seasonal field huts, rather than major Late Neolithic nucleated sites. It is maybe from such sites that the extensive land-use attested in the Sarló-hát diagrams was conducted. Despite the lack of evidence for local Late Neolithic sites, the lakeshore SH-WOOD pollen profile provided evidence for a major change in the scale of floodplain exploitation. For the first time, the expansion of floodplain, lakeshore pastures shows more intensive pastoralist and arable clearances than in the AVK phase.

The second explanation was that there was not even limited, seasonal occupation in these zones – perhaps because of slightly moister summers causing a slight rise in Sarló-hát lake levels and longer stay of the seasonal floods in the alluvium. Instead, the area beyond the intensively cultivated ‘infield’ of the Czőszhalom tell was utilised first for a limited amount of (apparently manure-free) cultivation and then, around Sarló-hát, as an extensive zone of pastoral land-use, with cowherds being careful not to discard Late Neolithic pottery, integrated with far more restricted arable cultivation. The three small Late Neolithic sites near Sarló-hát could have acted as subsidiary sites to the Csőszhalom tell in extensive subsistence practices. This proposal has the advantage of accounting for the pollen data. It is also consonant with the expanded scale of Late Neolithic agro-pastoralism and particularly the emphasis on cattle husbandry, which was more noticeable on the horizontal ('domestic') site than on the Csőszhalom ('ritual') tell (Schwartz in Raczky et al. 2002).

The extension of our considerations to the macro-territory of the Csőszhalom tell has implications for the social structure of the tell in the Late Neolithic, viz., the possibility that the substantial cattle herds pastured in the tell macro-territory (10 km radius) were owned by significant lineages, households or individuals living in the horizontal site, if not on the tell itself. It is impossible at this juncture to make a precise calculation of the size of these herds but an initial estimate has been attempted, based on the contribution of the pollen in the Csőszhalom macro-territory to the Sarló-hát diagram (Chapman et al. in prep.). Assuming the grazing intensity of one head of cattle per 1.2 ha, the use of 20% of a 3 km territory around the tell would have provided sufficient fodder for over 400 cattle. But if the territory is extended to a 6 km radius, the herd size could have increased to over 1,800 head. The extra-local pollen for open grassland in the Sarló-hát diagram is consistent with large open areas in the tell macro-territory capable of supporting an extensive strategy of cattle herding by the 5th millennium BC. These estimates are reminiscent of Sherratt's answer to the question 'what did plains-dwellers provide in exchange for upland resources in the Late Neolithic?' – large herds of cattle, as mobile wealth on the hoof (Sherratt 1982). This scenario would fit well with the amount of exotic material deposited at Csőszhalom. The Sarló-hát pollen diagram is the first diagram located within the macro-territory of a Late Neolithic nucleated site and is therefore the first with evidence for the large-scale animal husbandry long suspected of the period (Bökönyi 1959, 1974).

Copper Age dispersion and cattle husbandry

The subsequent Early Copper Age is represented by minor discard on the Sarló-hát meander shores. These sites probably represent the high residential mobility typical for much of the Early Copper Age. In this phase, there was a larger number of settlement clusters, which were separated from each other by smaller tracts of land (Parkinson 2006). While the ECA settlement clusters covered larger areas, there were more sites in a cluster and the sites were smaller than in the Late Neolithic.
The pollen record suggested an even moister alluvium than in the Late Neolithic, with a less pronounced summer water table fluctuation. We inferred episodic, fire-generated woodland clearances as the main impact on the alluvial vegetation, while decreasing wormwood (*Artemisia*) pollen frequencies and increasing Umbelliferae pollen percentages suggested a change in the composition of the floodplain pastures. There was a reduction in arable markers such as weeds of cultivation, which probably indicates a reduction in the scale of farming near the Sarló-hát. What appears to represent continuity from the Late Neolithic is the continuing use of floodplain pastures, even though their scale of use, too, was slightly reduced. The ECA changes in settlement structure at each integrative level, and in the direction of less complexity (Parkinson 2006), are likely to have resulted in changes in the scale of agro-pastoralist practices, whether in a major Early Copper Age cluster or in a re-occupied, small cluster, such as at Sarló-hát.

The scenario of major Late Neolithic cattle husbandry has implications for the Early Copper Age at Sarló-hát and more generally in the Hungarian Plain. Depending on the scale of Late Neolithic cattle husbandry, the move away from tell living and the division of nucleated groups capable of managing large herds of cattle into individual households meant a re-alignment of dwelling practices with land-use. In contrast to the Late Neolithic combination of nucleated people and dispersed agro-pastoral land-use, Early Copper Age groups were dispersed over the landscape in much the same way as their cattle and fields. It is hard to be sure that there was a major decline in the scale of cattle-keeping in the later period – or even less social differentiation between 'rich' farms with large cattle herds and 'poor' farms with small herds.

Neolithic subsistence and plant exploitation: comparisons between the pollen record and the Late Neolithic archaeo-botanical records of Polgár-Csőszhalom

During the excavations of two Neolithic sites in the Polgár area (Middle Neolithic Polgár 10: Gyulai 2010; Late Neolithic Csőszhalom tell and horizontal site; Fairbairn 1992, 1993; Raczky et al. 2002; Gyulai 2010) rich archaeo-botanical material was recovered through flotation. These settlement data provide a detailed picture on the arable economies of the Middle and Late Neolithic occupation period in this area. Additional file 1 summarizes these findings, together with the equivalent pollen types in the Sarló-hát pollen records.

On the basis of the diverse weed assemblages that included both dry- and wet ground taxa (e.g. *Papaver sp*., *Stipa sp*., *Solanum nigrum*, *Schoenoplectus lacustris*, *Juncus sp*.) Fairbairn argued that in the Middle Neolithic both dry- and wet-grounds were used for crop production (Fairbairn 1992). Both Fairbairn (1992) and Gyulai (2010) explained the dichotomy in the weed flora in terms of a risk management system, whereby the main crops were grown on the high floodplain to obtain high yields in 'dry' years, while a secondary crop was grown on the elevated lower yielding uplands ('Pleistocene lag surfaces' *sensu* Sümegi 2005) to ensure against total crop loss due to flooding of the alluvium. Fairbairn later slightly modified his conclusion concerning the risk-management system operating in the Late Neolithic and argued for the siting of fields along the Pleistocene riverbanks and elevated levees (Fairbairn 1993).

The Sarló-hát pollen records come from the high-yielding, but risky floodplain zone, and as we have pointed out above, they indicate small-scale crop farming in the alluvium during the Neolithic (mainly during the Szatmár II and Late Neolithic phases). We found low percentages of *Triticum* pollen (0.5-1%) accompanied by crop field weeds. This is in contrast with some alluvial sites in Poland and Souh-East Hungary, where near crop-field mires displayed 2-7% cereal pollen in the Neolithic layers (Wasylkova 1996; Willis 2007), but agrees with other alluvial sites, where crop fields were inferred to lie at a distance from the investigated meanders (Behre 2007). Our inference from this is that the majority of crop fields must have been located on the Pleistocene levees in the Polgár area, and the seasonally flooded alluvium was only opportunistically exploited for crop farming during the Neolithic. This inference accords with Fairbairn (1992) and Gyulai (2010), but the pollen data suggest only small-scale use of the alluvium for crop-farming. The relatively large proportion of wet-ground herbs in the settlement seed assemblages can probably be interpreted differently, as suggested by Kreuz et al. (2007) in connection with the Central European LBK sites. Accordingly, these wet-ground species could have been brought to the fields with the dung of cattle which grazed the floodplains as well as the harvested fields. Bogaard et al. (2008) also argued that, during the Early Neolithic of Hungary and the AVK, crop-fields were located near the settlements and managed with intensive labour input to maintain fertility, while floodplain soils were avoided. But Bogaard's intensive, local horticultural model may not be appropriate to the Late Neolithic, in which extensive agro-pastoral practices are clearly attested. The higher summer lake-levels attested in the Late Neolithic segment of the Sarló-hát pollen core would also have increased the risk of spring planting. There is no definitive evidence yet that high-yield, high-risk strategy of floodplain farming was not attempted in the Late Neolithic at times of nucleated population; in any case, it is recognised that there was always the back-up of a low-risk, low-yield strategy on the higher areas. Overall, it seems that, even in the Late Neolithic, fields were probably located in different parts of the landscape – on the Pleistocene lag surfaces for security and in the alluvium for spectacular high-yield successes as well as major failures. Moreover, evidence for probably other kinds of exploitation of the floodplain vegetation comes from on-site recovery of typical wetland plants, e.g. dwarf elder (*Sambucus ebulus*), giant bulrush (*Schoenoplectus lacustrsis*), reed (*Phraghmites australis*) and water dock (*Rumex hydrolapathum*) (Gyulai, 2010).

Comparison of the Csőszhalom plant-macro-fossils with the Sarló-hát Late Neolithic pollen flora suggests considerable variability in species cultivated, weeds of cultivation and pastoral indicators (Additional file 1). Despite many common elements, quite a few crop plants and weeds are missing from the pollen spectra. For example, *Pisum*, *Lathyrus/Vicia*-type and *Linum* were grown by the Late Neolithic settlers but they fail to show up in the alluvial pollen record. This may be because they are insect-pollinated or low pollen producers, or because of different cultivation practices for different species. Conversely, *Plantago lanceolata* seeds were present in the weed flora at Csőszhalom, while this pollen type also appeared in the Late Neolithic segment of the Sarló-hát core, suggesting that the alluvium around the meander was disturbed.

An overall reason for differences in species representativity may have been the varying taphonomic filters that applied to the preservation of on-settlement plant macro-fossils and those responsible for creating the pollen assemblage. But what is interesting is that there are so many identical species at Csőszhalom and Sarló-hát, suggesting that, in the Late Neolithic at least, there were comparable agro-pastoral practices in place, linking persons on and off the tell in daily subsistence and ritual tasks.

Neolithic human impact in Eastern Hungary: a regional comparison

The eastern part of Hungary comprises two contrasting landscape types: the Great Hungarian Plain, that has always been dominated by its watercourses and varying water availability dependent on the distance from watercourses; and the North Hungarian Mid-Mountains with its closed deciduous forests since at least the early Holocene (Figure 1b; Willis et al. 1997). From these two landscapes, five well-dated pollen records offer possibility for comparison (Kismohos (Willis et al. 1998), Nagymohos (Magyari et al. 2001), Sirok (Gardner 2002), Bábtava (Magyari et al. 2008) and Kiri-tó (Willis 2007), see Figure 1b), albeit only one of them (Ecsegfalva: Kiri-tó) comes from within 1 km of an excavated Early Neolithic site (Whittle 2007; Willis 2007). In the Neolithic period, all of these pollen records are characterized by hazel (*Corylus*) and oak (*Quercus*) dominance and notably all records show signs of Neolithic woodland management starting at slightly different dates. Figure 9 displays the early and mid Holocene parts of two NE Hungarian pollen records, Nagymohos from the Putnok Hills and Bábtava from the Bereg Plain, both area considered as a zone of low population density during the Neolithic (Sümegi 1999; Bánffy 2005), although the number of known archaeological sites in 50 km radius of both sites is high during the Middle Neolithic AVK and Bükk occupation phases (Bánffy 2005; Csengeri 2005). Moreover, recent excavations in the vicinity of Nagymohos recovered a small Middle Neolithic settlement of the Bükk culture, and painted pottery sherds probably from this settlement were found on the shores of Nagymohos (Csengeri 2005). Changes in these pollen records (starting at 7500 cal B.P. in Nagymohos and 7200 cal B.P. in Bábtava) involved periodic declines in hazel (*Corylus*) and elm (*Ulmus*), coincident increases in oak (*Quercus*) and ash (*Fraxinus excelsior* type) and increasing representation of disturbance indicator herbs (e.g., *Plantago lanceolata* at Nagymohos on Figure 9). These proxies were attributed to direct human activity (Magyari et al. 2001, 2008). Management of the woodland by coppicing of hazel, collection of leaves and young shoots of hazel and elm for leaf fodder and forest grazing were assumed. The similar saw-teeth shape of the hazel pollen frequency curve in the SH-WOOD pollen record (Figure 5) suggests a similar exploitation of hazel in the Körös and Szatmár II occupation phases (Early and Early Middle Neolithic) in the Upper Tisza Alluvium. Overall, it seems that woodland management can be traced in several pollen records in NE Hungary in the AVK occupation phase, and in case of Sarló-hát even earlier, since the start of the 6th millennium cal B.C. (ca. 8000 cal B.P.). In the Nagymohos pollen diagram, woodland management comes to a halt at ca. 6900 cal B.P. (4950 cal B.C.) (Figure 9), when increasing microcharcoal concentrations are accompanied by arboreal pollen decreases, suggesting forest clearance by burning. Similarly to SH-WOOD (Figure 5), wormwood (*Artemisia*) pollen frequencies show an episodic increase in the Late Neolithic, between ca. 6800-6500 cal B.P. (4850 – 4550 cal B.C.), pointing to a similar landscape management that likely involved more intensive grazing in the forest openings and woodland edges, but *Artemisia* can also indicate footpaths and fallows in the hill zone (Behre 1986; Fekete et al. 1997). Its mass occurrence was found somewhat earlier in SH-WOOD, between 7100-6700 cal B.P. (5150 – 4750 cal B.C.), but very characteristically it was also associated with forest clearance, and directly followed the woodland management phase. This suggests that this change in vegetation exploitation strategy is connectable with a technological and cultural change between the Middle and Late Neolithic. Delayed timing of both the woodland management and woodland clearance (to create grazing pastures) phases in the North Hungarian Mid Mountains is a clear feature of these pollen records, probably indicating a later spread of the Middle Neolithic AVK culture to the hills (represented by the Bükk culture) and also a delayed spread of the Late Neolithic groups and their subsistence strategy to the hill zone. This agrees with the archaeological interpretation of the Bükk culture as a late phase of the AVK (Kalicz and Makkay 1977). The settlement of the lower slopes of the Northern Mid Mountains from 4700 cal B.C., if not earlier (Raczky 1995; Pavúk 2007), by communities using Early Lengyel pottery means that the *Artemisia* rise in the Nagymohos pollen diagram may have reflected the grazing practices of these groups.

It is important to note, however, that the Bábtava diagram does not show an *Artemisia* increase in the Late Neolithic; instead, the woodland management phase is followed by an episodic spruce (*Picea*) and fern (Filicales) rise between 6800-6700 cal B.P. (4850 – 4750 cal B.C.), interpreted as a short-term cold episode or a by-product of recurrent fluvial activity (Magyari et al. 2008). Subsequently, human impact is weak in this record during the Late Neolithic, in line with the local archaeological evidence for scarce occupation.

Evidence for Late Neolithic and Copper Age woodland management was also found in the Sirok pollen profile derived from the Mátra Hills (Figure 1b). Here Gardner (2002) demonstrated periodically-reduced hazel pollen frequencies (72-288 years cycles) coincident with hornbeam (*Carpinus betulus*) pollen increases between 6900-5200 cal B.P. (4950 – 3550 cal B.C.) and interpreted these changes as reflecting regular coppicing or pollarding of hazel. The relatively late start of the woodland management agrees with the hinterland position of Sirok, but also provides evidence that coppicing was an important woodland exploitation method in the hill zone during the Late Neolithic, Early Copper Age and Middle Copper Age as well.

Turning to the south-eastern part of the Hungarian Plain, the pollen record of Kiri-tó (Figure 1b) has special importance, as it is located adjacent to an Early Neolithic Körös settlement whose cultural origins lie to the South (Whittle 2007). The pollen record was dominated by oak and hazel during the Körös occupation phase (8000-7500 cal B.P.), and Willis (2007) argued that inhabitants of the very small settlement exerted little impact on the forest composition, not even clearing woodland pockets on the alluvium or the loess-mantled elevated surfaces because there was enough open, steppe-covered area suitable for farming. Although evidence for Early Neolithic occupation is missing in the Sarló-hát area, our pollen records suggested stronger local human impact on the alluvial forest via selective felling and/or coppicing of hazel, small-scale clearance, and crop farming after 7600 cal B.P. (5650 cal B.C.). The general impression is that the impact of the Early Neolithic groups on the vegetation was larger in the northern part of the plain, probably because of the higher proportion of woodland here that required clearance.

Another important feature of the Kiri-tó pollen record was a significant reduction of arboreal pollen types and hence woodland cover after 7000 cal B.P. (5050 cal B.C.), that can be attributed to local AVK groups. As cereal pollen types also increased coincidently (attaining 5%) without an increase in wormwood (*Artemisia*) pollen, it is reasonable to assume that clearance was made to establish new crop fields and not grazing pastures. This feature of the Kiri-tó pollen record again differs from Sarló-hát, where the main impact of the AVK groups was the establishment of alluvial grazing. However, it is also possible that these landscape exploitation differences can be explained by the different position of the pollen coring sites relative to the main settlements, being nearer in the case of Kiri-tó. Consequently, crop fields were implicitly nearer to the pollen core location of the latter.

Disentangling climatic and human factors in the Sarló-hát Neolithic pollen record: short-term climate changes in East-Central Europe and the global climatic record

In this final part of the discussion, we make structured comparisons between the local proxy data, the Neolithic and Early Copper Age cultural phases of Eastern Hungary and the regional and global climatic trends, inferred from a range of climatic proxy records. Figure 10 shows these records. What is apparent for a first sight is the coincidence of the 8.2 ka cal B.P. cooling event (seen in the NGRIP $\delta^{18}O$, residual ^{14}C and PP10 stalagmite curves on Figure 10) with the organic content increase in SH-WOOD. Although the 8.2 event was associated with high lake levels in West-Central Europe due to the intensification of westerlies and lower summer temperatures

(Magny 2007), the East-Central European record of Lake St Ana (Magyari et al. 2009) suggests low water-depths with a minimum at 8.1 ka cal B.P. (6150 cal B.C.), in comparison with hints from the Sarló-hát record at enhanced seasonal water-level fluctuation with low summer water tables during this event. We also found increased fire frequencies. On the whole, our data suggest that the 8.2 ka event was associated with increased summer drought in the Carpathian Basin, but the underlying climatic circulation changes are yet unresolved to explain the discrepancy with West-Central Europe. The spread of the Körös Culture into the Carpathian Basin does not coincide with this climatic perturbation, but directly follows it (~ 7950 cal B.P.: ~ 6000 cal B.C.). The organic content record from SH-WOOD suggests that the lake basin stabilized in a different form after the 8.2 ka event; we inferred that, during the Körös and Szatmár II occupation phases, high spring floods were associated with high water temperatures, followed by strong summer drought and desiccation of the lakeshore. It is notable that the onset of the Szatmár II occupation phase (7450-7250 cal B.P.; 5500-5300 cal B.C.) coincides with a solar activity minimum (see the residual ^{14}C curve on Figure 10) and a concurrent high lake-level phase in West-Central Europe (Magny et al. 2003; Magny 2007). The SH-WOOD record also showed a minor increase in *Pediastrum* green algae (Figure 10) interpreted by us as a sign of increasing water-level, but the sustained high organic content and high *Cyperus* pollen percentages in the lake marginal SH-WOOD record suggested that the major trend of strong seasonal water level fluctuation persisted in this phase. The coincidence of a short-lived climatic change and a cultural change is nonetheless evident in this phase, and bivalve fauna based studies in the southern Tisza plain also support an environmental change at the onset of the early AVK, with stronger flood cycles leading into the dominance of fluvial bivalves on archaeological sites (Gulyás 2011).

At the onset of the Late Neolithic Tisza-Herpály-Csőszhalom (THCS) occupation phase, a remarkable coincidence is seen between the cultural change and the organic content plus galingale (*Cyperus*) pollen decreases in SH-WOOD (Figure 10) that implies slightly increasing summer water tables in the floodplain. Falling in a high solar activity phase that coincides with a period of low lake-levels in West-Central Europe (Figure 10), the Sarló-hát proxy records are apparently in mismatch with other climatic records. A possible interpretation of this discrepancy can be a change in the water budget of the floodplain. We may see a threshold situation here, whereby the gradually decreasing summer insolation and the PP10 stalagmite inferred gradual increase in convective rainfall over the Neolithic period (McDermott et al. 2011) in east-Central Europe (in this respect see also the gradually increasing lake level of St Ana) resulted in lower summer evapo-transpiration and hence increasing mid–late summer moisture availability in the floodplain zone after the recession of floods (without a need for stronger spring floods).

Finally, the onset of the Copper Age around 6550 cal B.P. (4600 cal B.C.) coincided with a marked increase in Umbelliferae pollen as a wet-meadow indicator in the lakeshore SH-WOOD profile and also with prominent changes in many European proxy records, e.g. with a solar activity minimum period and a high West-Central European lake levels phase that this time coincides with a further increase in Lake St Ana water depths (Figure 10). The overall impression is that the Tisza floodplain got wetter in the summer during the ECA, and this may bear a relation with the observed cultural and landscape exploitation strategies that involved settlement dispersion

(Parkinson 2006) and increased importance of animal husbandry relative to crop farming (Gyulai 2010).

On the whole, this comparison suggests an apparent accordance between cultural changes and climatic oscillations during the Neolithic and ECA. The Sarló-hát proxy records nevertheless show that the alluvial landscape and its vegetation did not respond to solar activity changes directly, as did the West-Central European lake levels (Magny et al. 2003). Rather, these effects were attenuated by the buffering capacity of the floodplain (e.g. during the Szatmár II phase) or prevailed through transmissions modulated by precipitation and temperature changes in the watershed of the Tisza river (e.g. during the ECA). What is less reliable is the inference that any of these climatic fluctuations actually caused the development of specific archaeological cultures. Most prehistoric groups did not live at the extremes of their subsistence possibilities but had a built-in buffering system to cope with unforeseen changes. The rather weak tendencies towards wetter or warmer conditions in the Great Hungarian Plain may have offered better potential for specific responses in terms of settlement or subsistence practices but we are far from demonstrating those inner socio-cultural links.

Conclusions

In this study, we used results from a carefully designed inter-disciplinary project seeking to integrate archaeology and palaeobotany. Results from a systematic archaeological survey were paired with pollen analysis from the Sarló-hát oxbow lake in the NE Great Hungarian Plain, where deposits covered the last 11,700 years cal BP (9750 cal BC) and provided well-preserved pollen that is rather exceptional in this semi-arid area. Dated by 12 AMS ^{14}C dates, this record is also exceptional in that it managed to overcome the problems of dating alluvial deposits of low organic content. We focused on the Neolithic and Early Copper Age vegetation changes and their implications for subsistence practices. Sarló-hát is adjacent to a large area with exceptionally good settlement pattern data from intensive, systematic fieldwalking and excavations due to motorway interventions. Several Neolithic and Copper Age sites/discards appear on the lakeshore in direct vicinity of the pollen core locations.
The results of this study allow us to draw the following main conclusions:

1) The Sarló-hát pollen records show without any doubt that the hitherto influential Willis and Bennett (1994) hypothesis that there was little human impact by farmers on the environment of SE Europe during the Neolithic is imprecise. While we documented small-scale agriculture in the earliest phases (coeval with Körös; Early Szatmár) in the Sarló-hát area, there are signs of expanding scale of mixed farming in the Middle Neolithic (AVK) and very good evidence for extensive landscape alterations with enhanced pasturing in the Late Neolithic and Early Copper Age. Thus, the strong contrast that Willis and Bennet (1994) drew between the Neolithic and the Bronze Age is fundamentally flawed. More attention to archaeological settlement forms would have made this finding more apparent. The main mitigating factor in revealing Neolithic human impact on the vegetation must have been the distance of most pollen records used in the Willis and Bennett (1994) study from Neolithic and Early Copper Age settlements.
2) We recognised, and sought explanations for, some major discrepancies between the pollen proxies for human impact and the archaeological patterns

of artefact discard, as a proxy for settlement. We found good fits between pollen and surface artefact discard for the Middle Neolithic AVK and Early Copper Age occupation phases. However, considerable mismatches were demonstrated for the Early Neolithic Körös and Late Neolithic THCS occupation phases. In case of the first, we explained the discrepancy by either the alluvial burial of small and hitherto undetected Körös/early Szatmár II sites or late Mesolithic impact. In case of the LN, the large-scale pastoral land use suggested by the SH-WOOD pollen record was explained by seasonal use of alluvial meadows by people living in dispersed homesteads in or near the alluvium or people living on large, but hitherto undetected horizontal settlements on the 'Tiszadob Island'.

3) Comparison with other well-dated pollen diagrams in Eastern Hungary (both on-site and off-site) pointed to several similarities in land use, such as hazel and elm coppicing in the Early and Middle Neolithic and more intensive evidence for pastoral activities and associated woodland clearance in the Late Neolithic. In addition, there were signs of regional variability, mainly in the scale and timing of agricultural practices – later and smaller-scale in the North Hungarian Mid-Mountains in comparison with the GHP. Some of this may well be related to the distance of Neolithic and ECA sites from the coring site; other elements include differences in the local environment.
4) Structured comparison with palaeoclimatic proxy records for the Neolithic and ECA suggest some general alignments between local environmental fluctuations documented at Sarló-hát and wider climatic fluctuations related to solar activity changes. Good matches between local and Northern Hemisphere climatic oscillations at the transitions to the Early Middle Neolithic (Szatmár II) and the ECA suggest links between cultural change and climate change. However, we found also mismatches which can be explained in terms of local buffering effects. The implication from this is that, rather than posing environmentally deterministic models of changing social practices, we have been able to suggest some periods when there were more direct responses to climatic fluctuations and other periods when various kinds of buffering – ecological mediations or intervening settlement or subsistence practices – were in operation.

One final implication from this study is that it is essential to have high-precision dating of both sets of data – archaeological and palaeobotanical. Pollen diagrams with many ^{14}C AMS (ideally over 10) dates and local settlement records with multiple AMS ^{14}C dates are essential. Without this, there is no possibility of making structured comparisons between these important data sets and thereby providing the basis not only for dating changes but also proposing causal relations between the changes.

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Figure legend

Fig. 1 Location of the study site. (a) Location of the study area in Europe. (b) Location of the Sarló-hát study site in NE Hungary. Other sites and regions mentioned in the text are also shown. Key to sites: 1. Kismohos, Nagymohos (Willis et al., 1997, 1998; Magyari et al., 2001); 2. Sirok (Gardner, 2002); 3. Bábtava (Magyari et al., 2008); 4. Sarló-hát (this study); 5. Ecsegfalva, Kiri-tó (Willis 2007); (c) Map of the Polgár Region showing the location of Sarló-hát oxbow lake, core locations (1. SH-II core; 2. SH-WOOD core) and other local place names mentioned in the text; (d) Second military survey map of the study region in which the Sarló-hát meander appears as a large swampy area, core locations are also shown (map made between 1806-1869, source: Arcanum 2006).

Fig. 2 Results of the archaeological survey in the Polgár Block indicating the position of Neolithic sites, stray discards, tell and horizontal settlements. Redrawn and modified from Chapman et al. (1994).

Fig. 3 Map of fieldwalked areas in the vicinity of the Sarló-hát meander showing the location of archaeological sites Dob 28-31, TG9 and sediment cores SH-II and SH-WOOD.

Fig. 4 Sarló-hát lithology and chronology. (a) Sediment lithology and organic content for the SH-II and SH-WOOD cores plotted against depth. (b) ^{14}C dates and Bayesian age–depth model constructed using Bchron (Parnell et al. 2008) for the SH-WOOD core. (c) local pollen assemblage zones (LPAZ) of SH-WOOD. ECA: Early Copper Age.

Fig. 5 Pollen percentage diagram for the SH-WOOD core, Sarló-hát, Tiszagyulaháza. Percentages of selected terrestrial pollen taxa are plotted against age (cal B.P.), the depth scale also being indicated. AP:NAP ratios, microcharcoal concentrations, palynological richness and sediment organic content are also shown. . ECA: Early Copper Age; THCS: Tisza-Herpály-Csőszhalom Cultures.

Fig. 6 Pollen percentage diagram for the SH-II core, Sarló-hát, Tiszagyulaháza. Percentages of selected terrestrial pollen taxa are plotted against age (cal B.P.), the depth scale also being indicated. AP:NAP ratios, palynological richness and sediment organic content are also shown. ECA: Early Copper Age; THCS: Tisza-Herpály-Csőszhalom Cultures.

Fig. 7 Percentage diagram of selected algae, aquatic and wetland pollen types from the SH-WOOD core, Sarló-hát, Tiszagyulaháza. Organic content is also shown. ECA: Early Copper Age; THCS: Tisza-Herpály-Csőszhalom Cultures.

Fig. 8 Cumulative percentages of pollen types reflecting different human land use types in the pollen records of SH-WOOD and SH-II, Sarló-hát, Tiszagyulaháza, Hungary. ECA: Early Copper Age; AVK: Alföld Linear Pottery Culture; THCS: Tisza-Herpály-Csőszhalom Cultures.

Fig. 9 Percentage diagram of selected pollen types for the Early and Mid Holocene from Nagymohos and Bábtava peat bogs (Magyari et al. 2001, 2008) and the number of Neolithic settlements in 50 km radius of the sites. For site locations see Figure 1b.

Fig. 10 Comparison between various Northern Hemisphere paleoclimate series and the SH-WOOD pollen, microcharcoal and organic content records. (1) 50 yr averaged NGRIP $\delta^{18}O$ proxy for temperature (North Greenland Ice Core Project members 2004); (2) residual ^{14}C data calculated from IntCal04 $\Delta^{14}C$ (%) with a 2000 yr moving average subtracted (Reimer et al. 2004); (3) PP10 stalagmite $\delta^{18}O$ record from Poleva Cave, SW Romania (Constantin et al. 2007); (4) Macrofossil based relative lake level changes in Lake St Ana, Romanian Carpathians; the curve shows a hydrological gradient from shallow to deep lake represented here by principal component axis 2 (Magyari et al. 2009); (5) High lake level phases in West-Central Europe according to Magny (2007); (6) organic content, relative frequencies of pollen types and green algae, ratio of arboreal and non-arboreal pollen (AP:NAP) and microcharcoal concentrations from SH-WOOD, Sarló-hát, NE Hungary (this study); (7) Summer (red curve) and winter (black curve) insolation values (W/m^2) at 60^oN (Berger and Loutre, 1991). ECA: Early Copper Age; THCS: Tisza-Herpály-Csőszhalom Cultures; Tiszapolg.: Tiszapolgár Culture.

Additional file 1 Comparative table of plant macrofossil taxa recorded by the archaeobotanical investigation of Late Neolithic settlements in the Polgár area and their equivalent pollen types in the Sarló-hát (SH-II, SH-WOOD) pollen diagrams. The Late Neolithic settlement, Polgár-10 was analysed by Fairbairn (1992, 1993) and the main core of the taxon list enumerates his data. In addition, taxa not found by Fairbairn but determined by Gyulai (2010) in course of an independent survey of the Csőszhalom tell are shown and marked (GY-CSH).

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Table 1 Selection of non-arboreal pollen types as anthropogenic indicators in the Neolithic section of cores SH-WOOD and SH-II, Sarló-hát, Tiszagyulaháza, Hungary. The category of land use was assigned to the pollen types following Behre (1981), Ujvárosi (1957) and Fekete et al. (1997). Grey fill indicates the inclusion of a taxon in the pooled pollen frequency sum of each land use category. On the right, natural plant communities are listed in which the species of the pollen type occur in the Middle Tisza Plain.

	Land use type and ecology						
Pollen type	Crop fields (Cereals)*	Crop fields (Weeds)	Fallow land / balk herbs	Footpath and ruderal vegetation	Wet pasture/ hey meadow	Dry pasture/ meadow	Natural communities in the Upper Tisza floodplain
Secale							*S. sylvestre*: calcareous sand steppes (unlikely in the area)
Triticum							-
Cirsium							marshy meadows, forest steppe, saline communities, alder carr
Polygonum aviculare							mudflat communities
Ambrosia-type							*X. strumarium*, pioneer mudflat and floodplain marsh communities
Melilotus							-
Potentilla							mudflat communities, tall sedge and tall herb wet meadows, marshy habitats, saline mud, forest steppe, sand steppe
Rumex acetosa /acetosella							sand steppe, dry meadows
Apium-type							wet floodplain meadows and marshy habitats
Bellis							-
Cannabis/Humulus							alder and willow carr, woodland edge
Cruciferae							reed swamp, wet meadows mainly
Euphorbia							oak-ash-elm forest edge, dry oak forest edge, sand steppes
Gentiana							wet floodplain meadows
Pedicularis							tall sedge fens
Peucedanum-type							alder carr, tall sedge fen, sand steppe, oak forest steppe, loess oak forest,
Plantago major-media							seasonally flooded meadows
Ranunculus acris							wet floodplain meadows
Ranunculus sp.							wet floodplain meadows, willow carr, tall sedge fen, saline steppe, dry oak forest, mudflat communities
Rumex sp.							reedswamp, wet alluvial meadows and marshy habitats, floodplain ruderal mudflat vegetation
Scabiosa							dry steppe
Stachys							oak-ash-elm forest, oak forest steppe, willow carr, reed swamp, tall sedge fen
Stellaria-type							includes several genera, wide distribution in floodplain plant communities
Umbelliferae*[1]							marshy oxbow lakeshores with summer-dry habitat (Rorippo-Oenanthetum), willow carr, alder carr, permanently wet-soil floodplain meadows
Artemisia					*A. vulgaris**[2]		saline wormwood steppe, saline tall herb wet meadow, forest steppe
Veronica							oak forest, alder carr, shallow oxbow lakeshores (Rorippo-Oenanthetum), tall herb fens, steppe meadows
Cerastium-type							saline wormwood steppe, sand steppe, floodplain meadows
Dianthus							sand steppe, forest steppe, saline tall herb wet meadow, meadow steppe
Filipendula vulgaris							tall herb wet meadows, loess oak forest steppe
Lotus-type							wormwood steppe, wet meadows
Verbascum							loess steppe
Chenopodiaceae*[3]							floodplain ruderal mudflat vegetation (seasonally flooded lakes and channels with organic debry accumulation hence high nutrient availability), wet saline meadows, saline lake bottoms, willow carr

* Poaceae > 40μm were not included because of the suspected presence of wetland Gramineae in this group (e.g. *Glyceria*)
*[1] includes *Oenanthe*, *Cicuta*, *Angelica* and Umbelliferae undifferentiated
*[2] *Artemisia vulgaris* is a typical constituent of disturbed tall herb wet floodplain meadows
*[3] Chenopodiaceae were not included in any land use category because of its suggested abundance in the natural mudflat communities (see the methods section)

Table 2 Pollen assemblage characteristics of Neolithic and Early Copper Age cultural periods in the SH-WOOD and SH-II pollen records (Figs. 5-8)

Cultural period	**Age**	**Characteristics of cultural period** (principal or distinctive pollen, microcharcoal, palynological richness)
Early Neolithic Körös	**7950 – 7450 cal B.P. 6000 – 5500 cal B.C.**	Strong relative frequency fluctuation of *Corylus* (SH-WOOD: 12-23%, av. 18%, SH-II: 22.5-33%, av. 28%) and *Quercus* (SH-WOOD: 21-30%, av. 25%, SH-II: 11.5-21%, av. 17%) in both records; *Fagus* increase in SH-II (max.1%); Chenopodiaceae increase in SH-WOOD, decrease in SH-II; *Anthemis*-type increase in SH-WOOD; *Triticum*-type pollen is present in SH-WOOD; *Cyperus* and Cyperaceae pollen maximum in SH-WOOD; decreasing microcharcoal concentration in SH-WOOD; AP:NAP ratio decrease in SH-WOOD, increase in SH-II; palynological richness ranges 20-22 in SH-WOOD and 21-23 in SH-II
Middle Neolithic Szatmár II, Early AVK	**7450 – 7250 cal B.P. 5500 -5300 cal B.C.**	*Corylus* (SH-WOOD: 16-19%, av. 18%, SH-II: 19%) and *Quercus* (SH-WOOD: 17-32%, av. 24.8%, SH-II: 24%) relative frequency fluctuation in both records but in different direction; *Triticum*-type, *Secale* and crop filed weed pollen present in SH-II, while *Triticum* and crop field weed pollen in SH-WOOD; Apophyta pollen and *Artemisia* increase in SH-WOOD; AP:NAP ratio minimum in both records; microcharcoal concentration peak in SH-WOOD; palynological richness ranges 22.5-25 in SH-WOOD and 21-25 in SH-II.
Middle Neoltihic Late AVK	**7250 – 6950 cal B.P. 5300 – 5000 cal B.C.**	*Fraxinus excelsior/angustifolia* type pollen increase in SH-WOOD (max. 5.2%); *Carpinus betulus* episodic increase in SH-II (3%); *Artemisia* increase in SH-WOOD (from 4.5 to 10%); wet meadow and dry pasture indicator herb increase in SH-WOOD, but decrease in SH-II after an initial peak; *Triticum*-type and *Secale* pollen present in SH-WOOD; foothpath and ruderal herb increase in SH-II; AP:NAP ratio decrease following an episodic increase at 7230 cal B.P. in SH-WOOD, AP:NAP ratio increase in SH-WOOD; palynological richness ranges 22.5-25 in SH-WOOD and 18.5-24 in SH-II; *Corylus* pollen frequencies in SH-WOOD: 20.3-20.7%, av. 20.5%, in SH-II: 25.2-25.6%, av. 25.4%; *Quercus* pollen frequencies in SH-WOOD: 16-24%, av. 21%, in SH-II: 15-17%, av. 16%
Late Neolithic Tisza-Herpály-Csőszhalom	**6950 – 6450 cal B.P. 5000 – 4500 cal B.C.**	Further increase in *Artemisia* relative frequencies in SH-WOOD (max. 11.4%), but not in SH-II; stable *Corylus* (SH-WOOD:18.7-23% ; SH-II: 27-30%) and *Quercus* pollen frequencies (SH-WOOD: 18-21%; SH-II: 16.2-18%); *Carpinus betulus* gradual increase in SH-WOOD (max. 2%); generally low, but fluctuating AP:NAP ratios (SH-WOOD: 1.4-2.3, SH-II: 2.8-3.1); single microcharcoal concentration peak at 6830 cal B.P. (4880 cal B.C.) in SH-WOOD; wet meadow and dry pasture herbs increase in SH-WOOD until 6730 cal B.P. (4780 cal B.C.), decrease afterwards; *Triticum*-type and *Secale* present in SH-WOOD; *Cyperus* and Cyperaceae pollen frequency decrease in SH-WOOD; palynological richness ranges 24-29.5 in SH-WOOD and 18.5-23 in SH-II
Early Copper Age Tiszapolgár	**6450 – 5950 cal B.P. 4500 – 4000 cal B.C.**	*Quercus* relative frequencies increase in SH-II (max. 25.6%), Corylus decrease in SH-II (from 30% to 19%); Umbelliferae increase in SH-WOOD (from 2 to 7%); significant AP:NAP ratio decrease in SH-WOOD (from 2 to 1.4), and small-scale decrease in SH-II; microcharcoal concentration maximum at 6100 cal B.P. (4150 cal B.C.) and subsequent increase in *Fraxinus excelsior*/*angustifolia* pollen in SH-WOOD; *Triticum*-type and *Secale* pollen present in SH-II; meadow indicators are high in SH-WOOD and gradually increase in SH-II; small increase in *Sparganium*/*Typha angustifolia* pollen in SH-WOOD; palynological richness ranges 21-27 in SH-WOOD and 20-25.5 in SH-II

Plant remains from Late Neolithic sites in the Polgár Area	Equivalent pollen types in SH-II & SH-WOOD
Domestic plants	
Triticum monococcum	*Triticum*-type
Triticum dicoccum	
Triticum turgidum/durum	
Triticum aestivum	
Triticum compactum	
Hordeum vulgare	Cereales > 40 μm
Avena sp.	– (*Avena*-type)
Panicum miliaceum (GY-CSH)	Gramineae
Lens sp.	– (*Lathyrus*/*Vicia*)
Pisum sativum	– (*Pisum*)
Pisum elatius	
Vicia spp.	– (*Lathyrus*/*Vicia*)
Vicia cf. *V. sativa* (GY-CSH)	
Linum usitatissimum	– (*Linum*)
Wild plants	
Polygonum arenastrum	*Polygonum aviculare*-type
Hordeum bulbosum (GY-CSH)	Cereales > 40 μm
Polygonum cf. *P. persicaria*	*Polygonum persicaria*-type
Fallopia convolvulus	– (*Fallopia convolvulus*)
Chenopodium hybridum	Chenopodiaceae
Chenopodium polyspermum	
Chenopodium vulparia	
Chenopodium murale	
Chenopodium album	
Chenopodium/Atriplex spp.	
Papaver spp.	*Papaver*
Solanum nigrum	*Solanum nigrum/Physalis*
Galium sp.	*Galium*
Galium cf. verum	
Galium cf. palustre	
Gramineae indet.	Gramineae
Bromus spp.	
Phleum sp.	
Phalaris sp.	
Stipa sp.	
Setaria sp.	
Schoenoplectus lacustris	Cyperaceae
Carex spp.	
Juncus spp.	*Juncus*
Caryophyllaceae spp.	Caryophyllaceae undiff.
Stellaria media/Cerastium sp.	*Cerastium*-type/*Stellaria*-type
Sagina sp.	*Sagina*
Lychnis sp.	*Lychnis*-type
Silene sp. (CSH)	*Silene*
Fragaria sp.	*Fragaria*
Prunella vulgaris	*Prunella*
Liliaceae indet.	– (Liliaceae undiff.)
Dryopteris filix-mas	*Drypteris*
Rumex acetosella (CSH)	*Rumex acetosa/acetosella*
Rumex sp. (CSH)	*Rumex sp.*
Rumex hydrolapathum (GY-CSH)	
Potentilla sp. (CSH)	*Potentilla*
Leguminoseae indet. (CSH)	Leguminoseae undiff.
Compositae indet. (CSH)	Compositae Subfamily Liguliflorae / Compositae Subfamily Tubuliflorae
Trees & Shrubs	
Corylus sp.	*Corylus*
Prunus cf. *P. spinosa*	*Prunus*
Cornus mas	*Cornus mas*
Sambucus nigra	*Sambucus*

Additional file 1 Comparative table of plant macrofossil taxa recorded by the archaeobotanical investigation of Late Neolithic settlements in the Polgár area and their equivalent pollen types in the Sarló-hát (SH-II, SH-WOOD) pollen diagrams. The Late Neolithic settlement, Csőszhalom was analysed by Fairbairn (1992, 1993) and the main core of the taxon list enumerates his data. In addition, taxa not found by Fairbairn but determined by Gyulai (2010) in course of an independent survey of the Csőszhalom tell are shown and marked (GY-CSH).

Figure 1

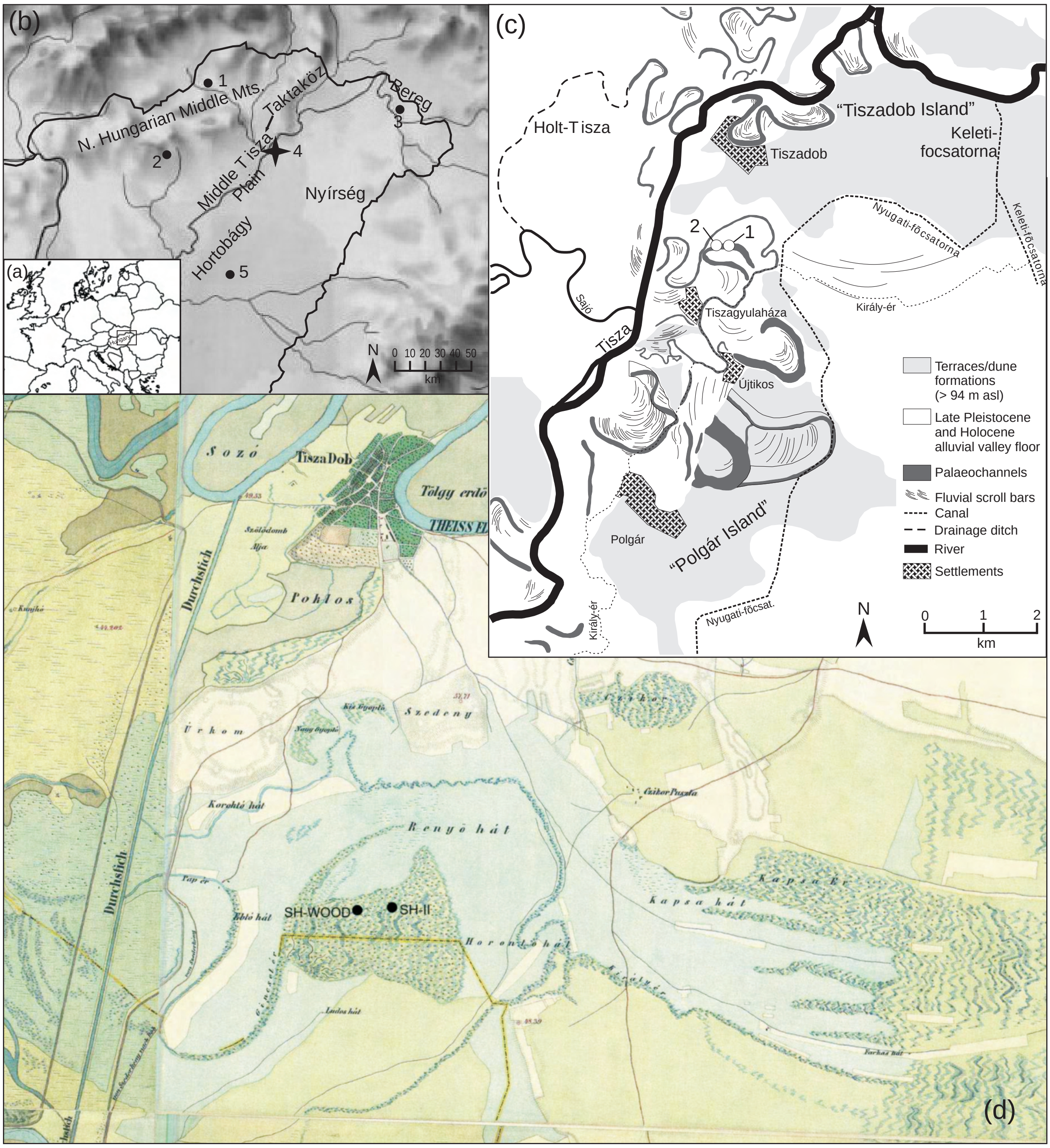

(b)
N. Hungarian Middle Mts.
Taktaköz
Bereg
Middle Tisza Plain
Nyírség
Hortobágy
1
2
3
4
5
N
0 10 20 30 40 50
km
(a)
(c)
"Tiszadob Island"
Holt-Tisza
Tiszadob
Keleti-focsatorna
Nyugati-főcsatorna
Keleti-főcsatorna
Király-ér
Sajó
Tisza
Tiszagyulaháza
Újtikos
Polgár
"Polgár Island"
Nyugati-főcsat.
Terraces/dune formations (> 94 m asl)
Late Pleistocene and Holocene alluvial valley floor
Palaeochannels
Fluvial scroll bars
Canal
Drainage ditch
River
Settlements
N
0 1 2
km
(d)
TiszaDob
Tölgy erdő
THEISS FL
Durchstich
Pohlos
Szedeny
Renyó hát
Kapsa hát
SH-WOOD
SH-II

Figure 2

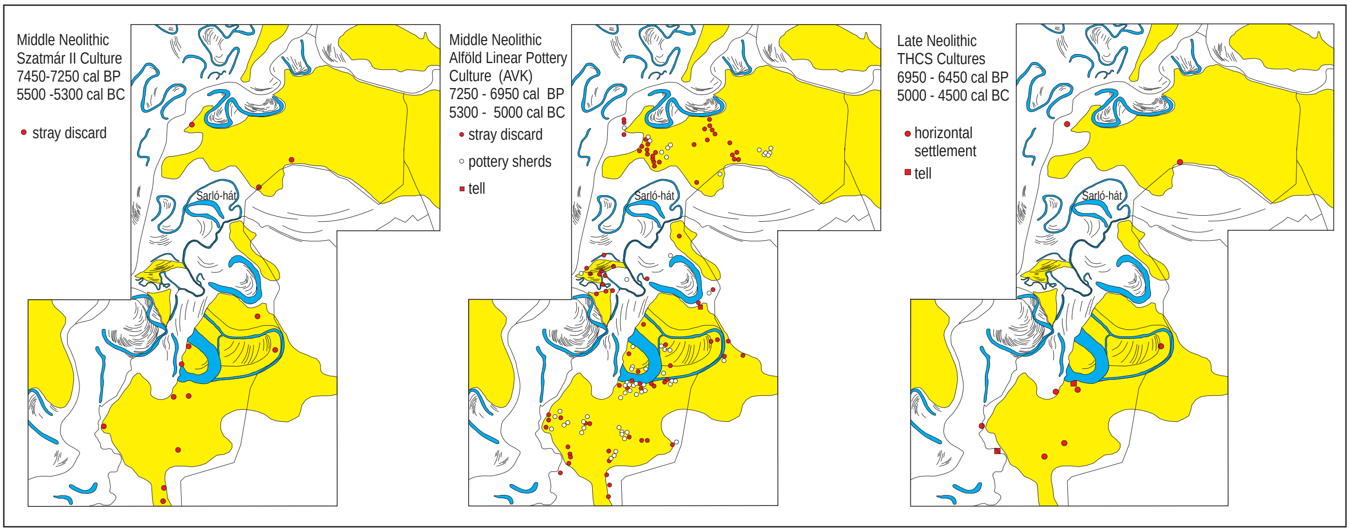

Middle Neolithic
Szatmár II Culture
7450-7250 cal BP
5500 -5300 cal BC
stray discard
Sarló-hát
Middle Neolithic
Alföld Linear Pottery
Culture (AVK)
7250 - 6950 cal BP
5300 - 5000 cal BC
stray discard
pottery sherds
tell
Sarló-hát
Late Neolithic
THCS Cultures
6950 - 6450 cal BP
5000 - 4500 cal BC
horizontal
settlement
tell
Sarló-hát

Figure 3

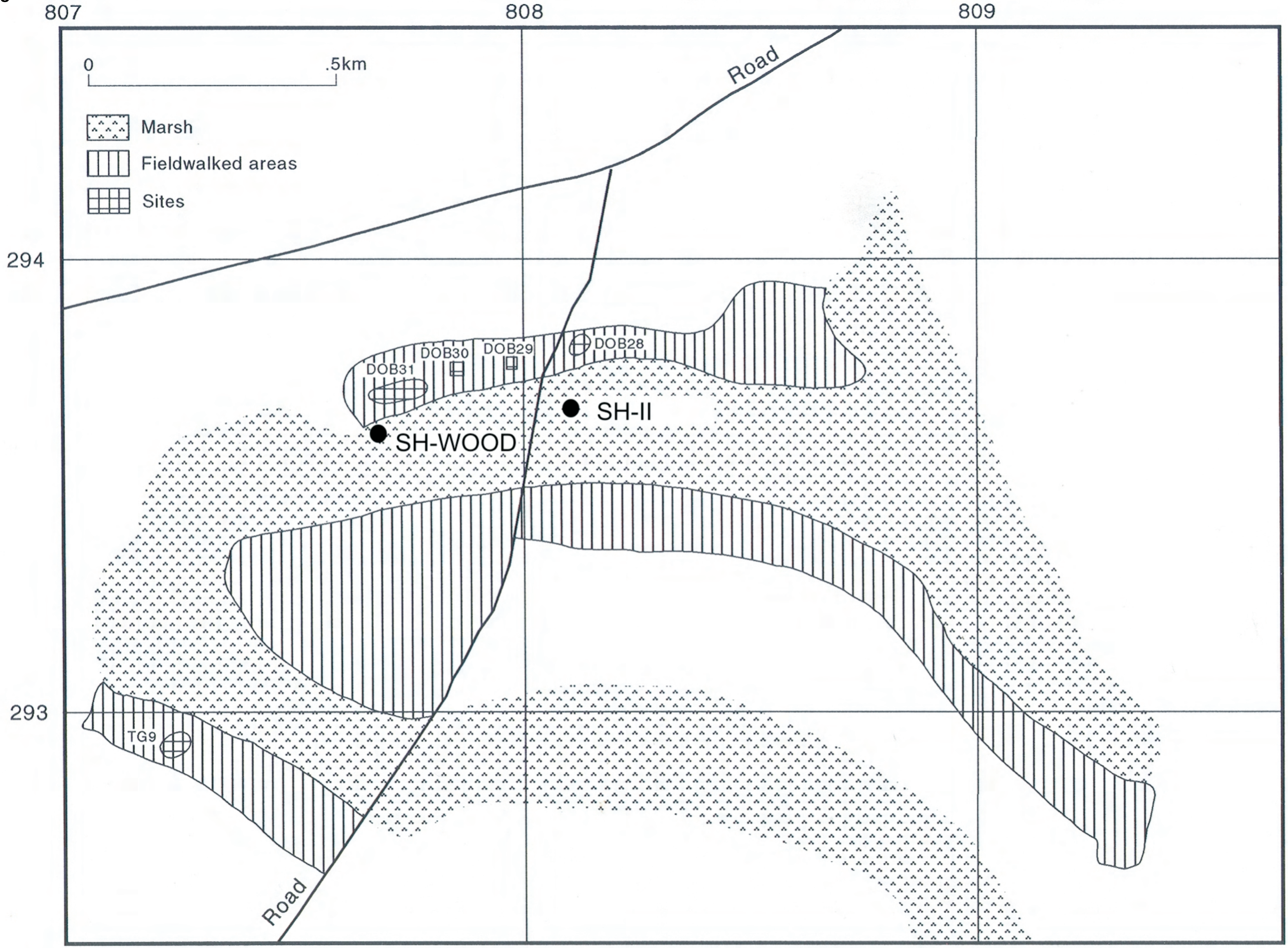
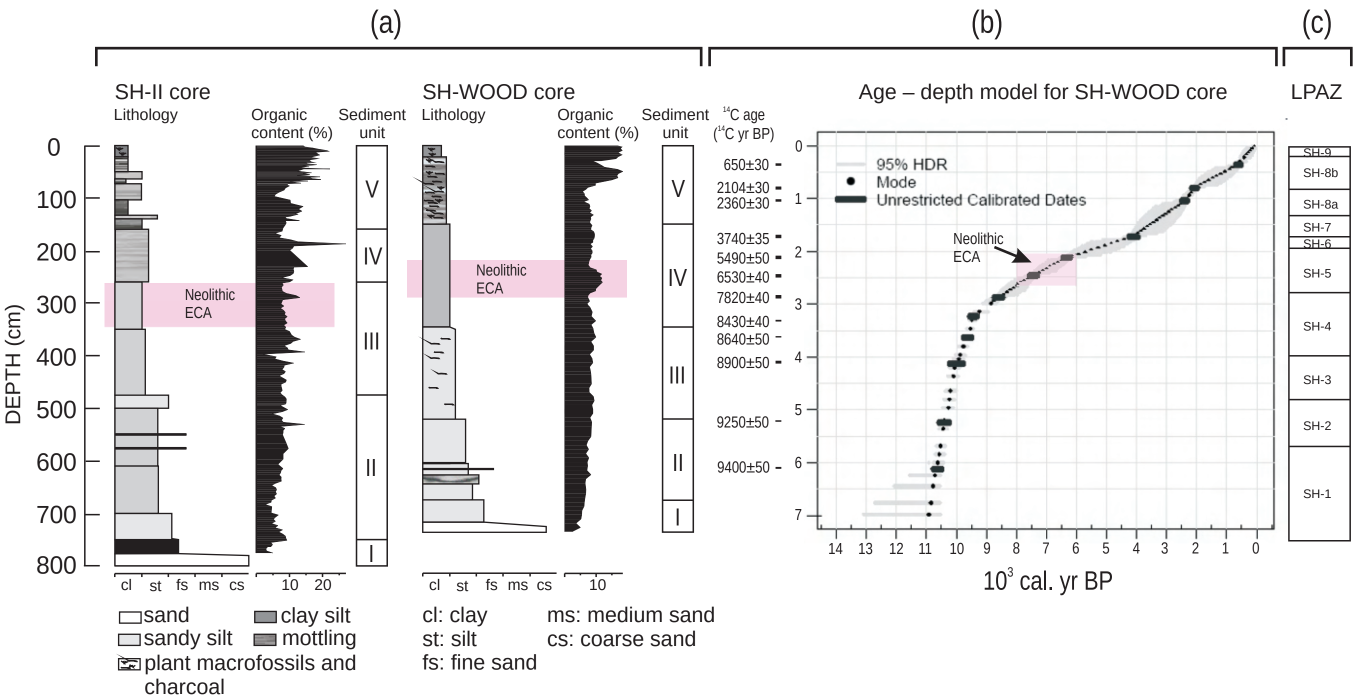
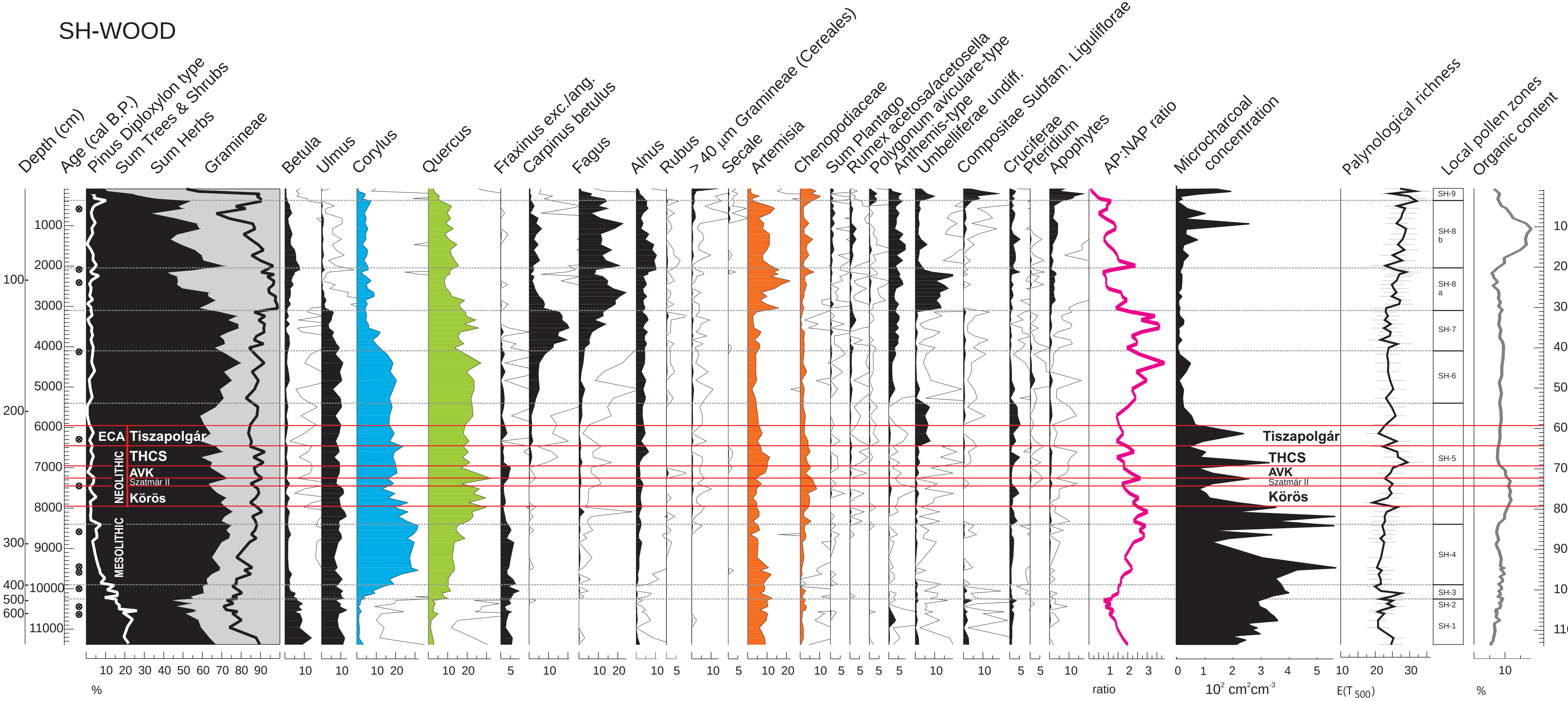

807
808
809
294
293
0
.5km
Marsh
Fieldwalked areas
Sites
Road
Road
DOB28
DOB29
DOB30
DOB31
SH-II
SH-WOOD
TG9

Figure 4



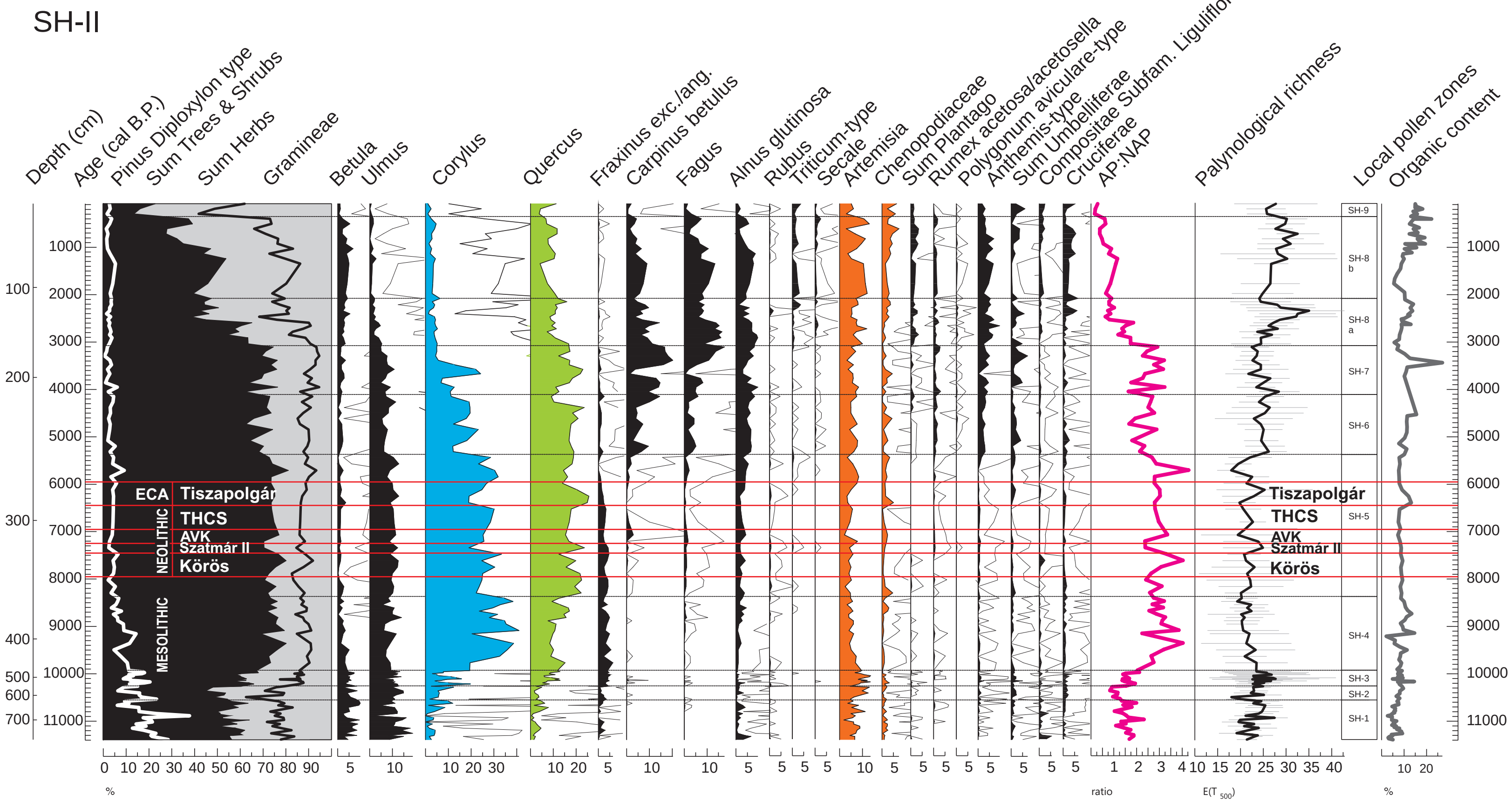
(a)
(b)
(c)
SH-II core
Lithology
Organic content (%)
Sediment unit
SH-WOOD core
Lithology
Organic content (%)
Sediment unit
Age – depth model for SH-WOOD core
LPAZ
DEPTH (cm)
Neolithic ECA
V
IV
III
II
I
cl st fs ms cs
10 20
10
14C age (14C yr BP)
650±30
2104±30
2360±30
3740±35
5490±50
6530±40
7820±40
8430±40
8640±50
8900±50
9250±50
9400±50
95% HDR
Mode
Unrestricted Calibrated Dates
10³ cal. yr BP
SH-9
SH-8b
SH-8a
SH-7
SH-6
SH-5
SH-4
SH-3
SH-2
SH-1
sand
sandy silt
clay silt
mottling
plant macrofossils and charcoal
cl: clay
st: silt
fs: fine sand
ms: medium sand
cs: coarse sand

Figure 5



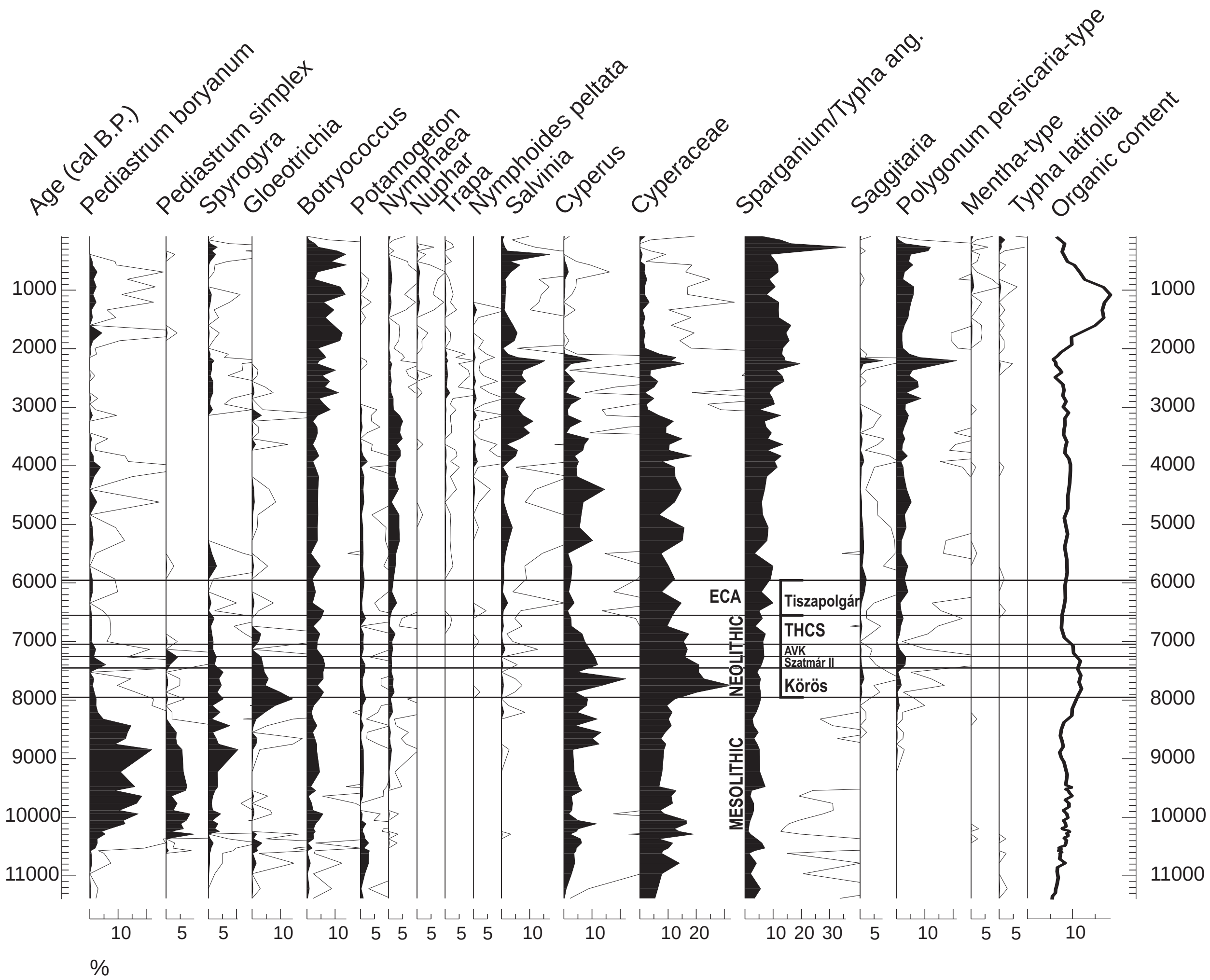
SH-WOOD
Depth (cm)
Age (cal B.P.)
Pinus Diploxylon type
Sum Trees & Shrubs
Sum Herbs
Gramineae
Betula
Ulmus
Corylus
Quercus
Fraxinus exc./ang.
Carpinus betulus
Fagus
Alnus
Rubus
> 40 µm Gramineae (Cereales)
Secale
Artemisia
Chenopodiaceae
Sum Plantago
Rumex acetosa/acetosella
Polygonum aviculare-type
Anthemis-type
Umbelliferae undiff.
Compositae Subfam. Liguliflorae
Cruciferae
Pteridium
Apophytes
AP:NAP ratio
Microcharcoal concentration
Palynological richness
Local pollen zones
Organic content
ECA
Tiszapolgár
THCS
AVK
Szatmár II
Körös
NEOLITHIC
MESOLITHIC
SH-9
SH-8 b
SH-8 a
SH-7
SH-6
SH-5
SH-4
SH-3
SH-2
SH-1
%
ratio
10^2 cm^{2}cm^{-3}
E(T 500)

Figure 6



SH-II
Depth (cm)
Age (cal B.P.)
Pinus Diploxylon type
Sum Trees & Shrubs
Sum Herbs
Gramineae
Betula
Ulmus
Corylus
Quercus
Fraxinus exc./ang.
Carpinus betulus
Fagus
Alnus glutinosa
Rubus
Triticum-type
Secale
Artemisia
Chenopodiaceae
Sum Plantago
Rumex acetosa/acetosella
Polygonum aviculare-type
Anthemis-type
Sum Umbelliferae
Compositae Subfam. Liguliflorae
Cruciferae
AP:NAP
Palynological richness
Local pollen zones
Organic content
ECA
Tiszapolgár
NEOLITHIC
THCS
AVK
Szatmár II
Körös
MESOLITHIC
SH-9
SH-8 b
SH-8 a
SH-7
SH-6
SH-5
SH-4
SH-3
SH-2
SH-1
%
ratio
E(T 500)

Figure 7



Age (cal B.P.)
Pediastrum boryanum
Pediastrum simplex
Spyrogyra
Gloeotrichia
Botryococcus
Potamogeton
Nymphaea
Nuphar
Trapa
Nymphoides peltata
Salvinia
Cyperus
Cyperaceae
Sparganium/Typha ang.
Saggitaria
Polygonum persicaria-type
Mentha-type
Typha latifolia
Organic content
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
11000
ECA
NEOLITHIC
MESOLITHIC
Tiszapolgár
THCS
AVK
Szatmár II
Körös
10
5
5
10
10
5
5
5
5
5
10
10
10 20
10 20 30
5
10
5
5
10
%

Figure 8

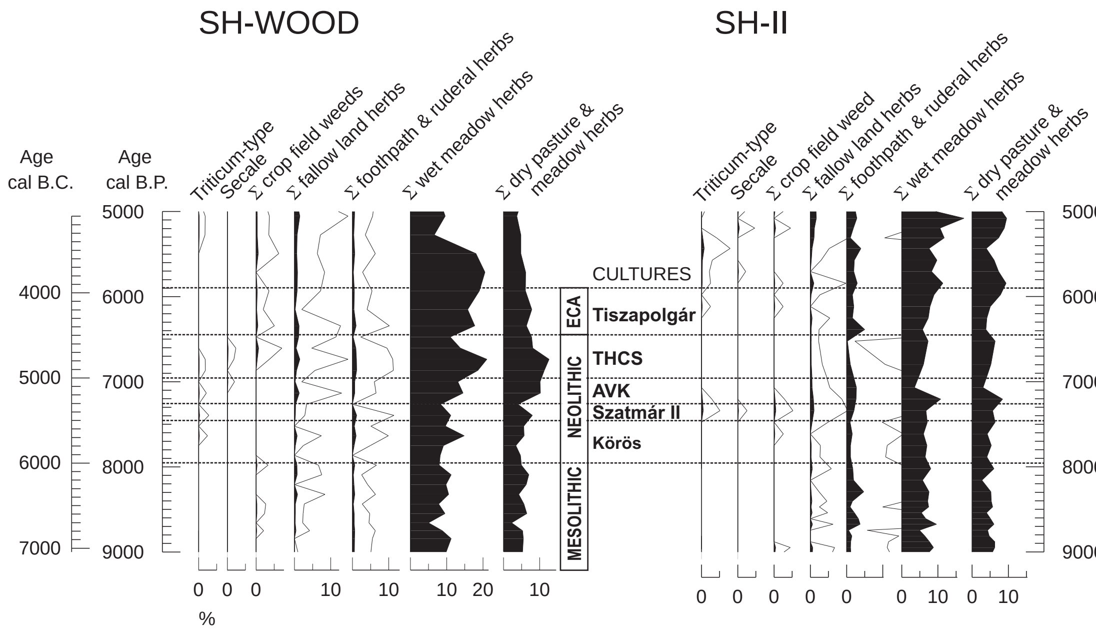

SH-WOOD
SH-II
Age cal B.C.
Age cal B.P.
Triticum-type
Secale
Σ crop field weeds
Σ fallow land herbs
Σ foothpath & ruderal herbs
Σ wet meadow herbs
Σ dry pasture & meadow herbs
Σ crop field weed
4000
5000
6000
7000
5000
6000
7000
8000
9000
CULTURES
ECA
NEOLITHIC
MESOLITHIC
Tiszapolgár
THCS
AVK
Szatmár II
Körös
0
10
20
%

Figure 9

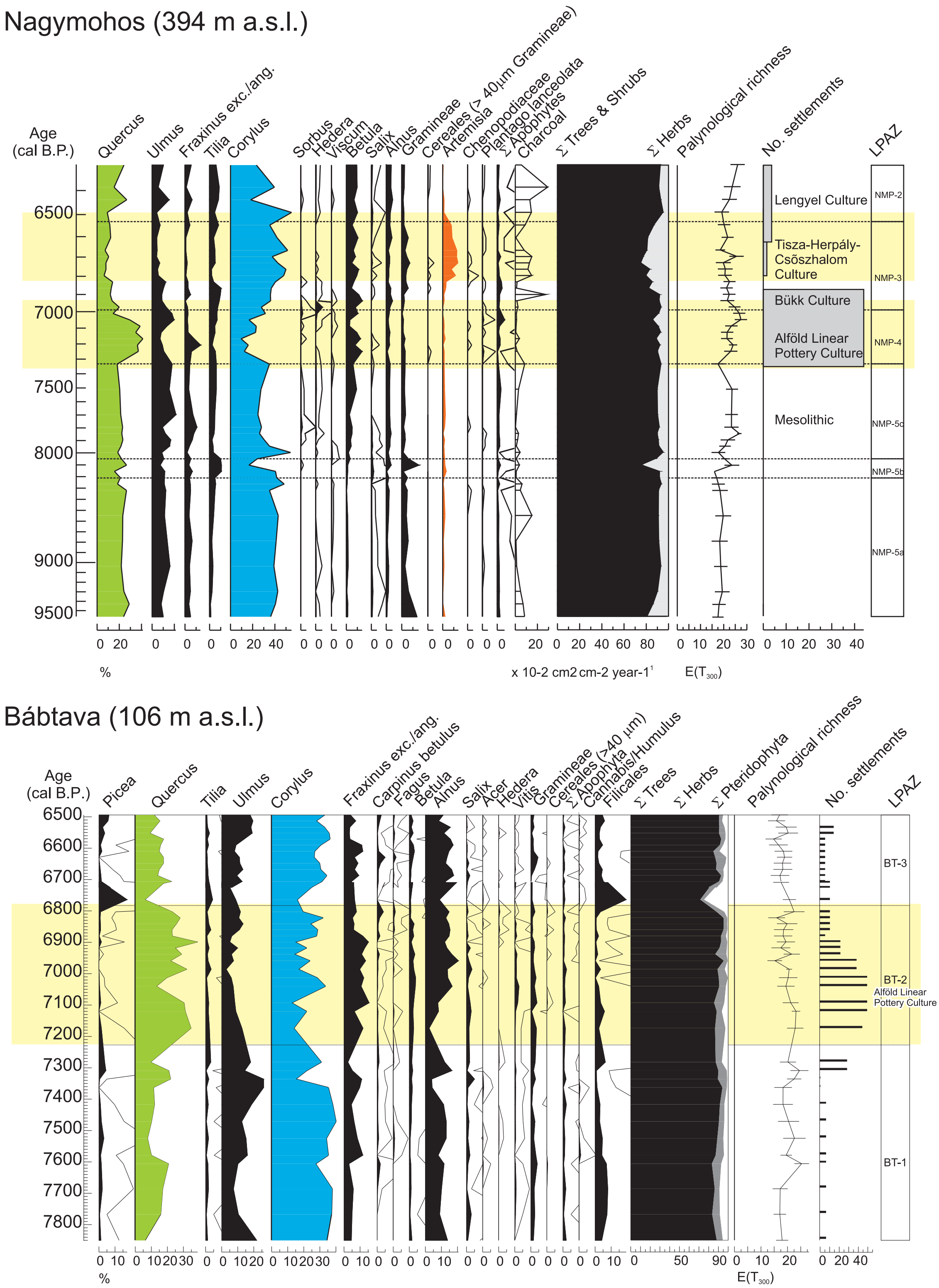
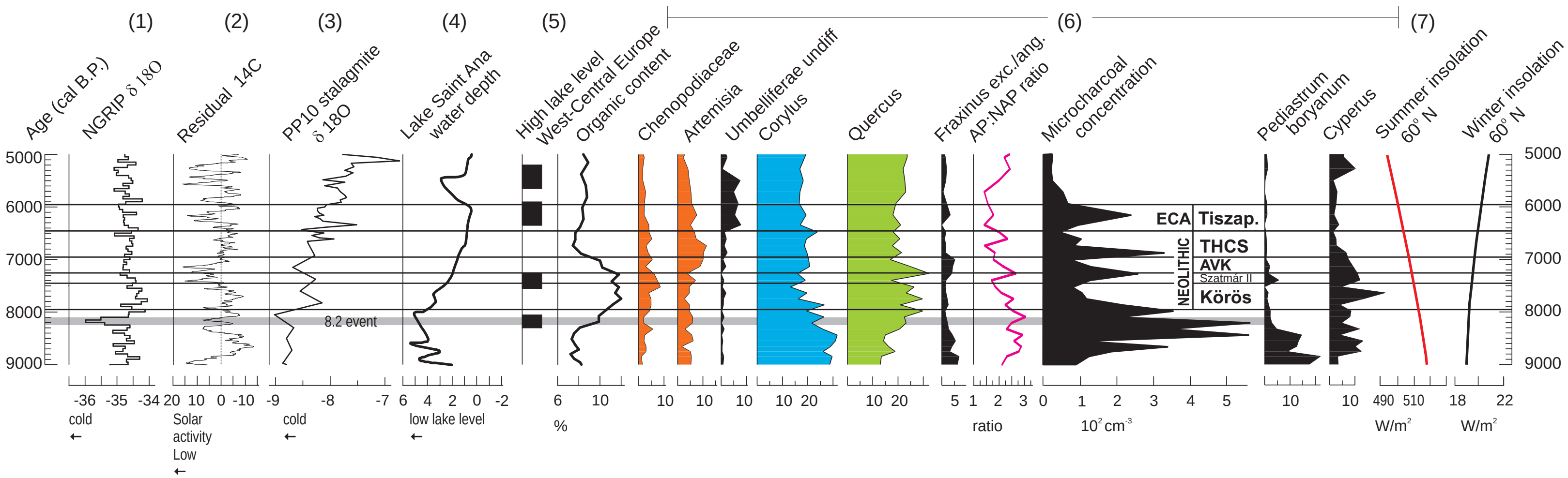

Nagymohos (394 m a.s.l.)
Age (cal B.P.)
Quercus
Ulmus
Fraxinus exc./ang.
Tilia
Corylus
Sorbus
Hedera
Viscum
Betula
Salix
Alnus
Gramineae
Cereales (> 40µm Gramineae)
Artemisia
Chenopodiaceae
Plantago lanceolata
Σ Apophytes
Charcoal
Σ Trees & Shrubs
Σ Herbs
Palynological richness
No. settlements
LPAZ
Lengyel Culture
Tisza-Herpály-Csõszhalom Culture
Bükk Culture
Alföld Linear Pottery Culture
Mesolithic
NMP-2
NMP-3
NMP-4
NMP-5c
NMP-5b
NMP-5a
%
x 10-2 cm2 cm-2 year-1
E(T300)
Bábtava (106 m a.s.l.)
Age (cal B.P.)
Picea
Quercus
Tilia
Ulmus
Corylus
Fraxinus exc./ang.
Carpinus betulus
Fagus
Betula
Alnus
Salix
Acer
Hedera
Vitis
Gramineae
Cereales (>40 µm)
Σ Apophyta
Cannabis/Humulus
Filicales
Σ Trees
Σ Herbs
Σ Pteridophyta
Palynological richness
No. settlements
LPAZ
BT-3
BT-2
Alföld Linear Pottery Culture
BT-1
%
E(T300)

Figure 10



(1)
(2)
(3)
(4)
(5)
(6)
(7)
Age (cal B.P.)
NGRIP δ 18O
Residual 14C
PP10 stalagmite δ 18O
Lake Saint Ana water depth
High lake level West-Central Europe
Organic content
Chenopodiaceae
Artemisia
Umbelliferae undiff
Corylus
Quercus
Fraxinus exc./ang.
AP:NAP ratio
Microcharcoal concentration
Pediastrum boryanum
Cyperus
Summer insolation 60° N
Winter insolation 60° N
8.2 event
ECA
Tiszap.
NEOLITHIC
THCS
AVK
Szatmár II
Körös
cold
Solar activity Low
cold
low lake level
%
ratio
10^2 cm^{-3}
W/m^2
W/m^2